131. Further Investigation of Grapefruit Juice Flavor Components (*Citrus paradisi* MACFAYDEN). Valencane- and Eudesmane-type Sesquiterpene Ketones

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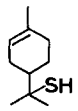
Dedicated to Prof. *Edgar Lederer* on the occasion of his 75th birthday

(4.V.83)

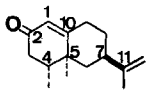
Summary

Fourteen sesquiterpene ketones **D**–**Q** pertaining to the valencane (**D**–**J**) and eudesmane (**K**–**Q**) groups have been identified for the first time in grapefruit juice flavor. These novel grapefruit constituents, which include the six new compounds **I**, **J**, **L**, **M**, **N** and **O**, were identified by direct comparison with synthetic samples. Organoleptically, their total contribution to grapefruit flavor is not negligible. In particular, (+)-8,9-didehydronootkatone (**E**) has a powerful flavor with good grapefruit juice character.

We have previously shown that 1-*p*-menthene-8-thiol (**A**) is an extremely powerful character-impact constituent which occurs at or below the ppb-level in grapefruit juice [1]. Another specific part of grapefruit flavor may be due to (+)-nootkatone (**B**) [2][1])[2]) but, besides this ketone, other unknown constituents possibly related to it seem also to contribute significantly to the overall grapefruit



A



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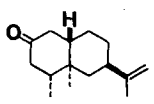


C

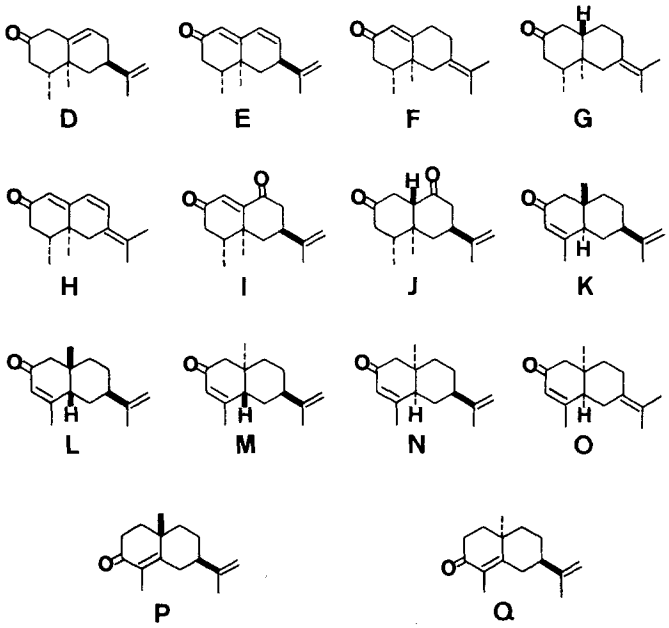
aroma. This was clearly suggested by the observation that the mother liquor from which natural (+)-nootkatone (**B**) is crystallized has better grapefruit-like character than pure **B** [5]. We have now confirmed this assumption by identifying the ses-

[1]) The numbering system [3] in formula **B** will be applied to all valencane- and eudesmane-type compounds throughout this paper. Systematic names of ketones **I**–**O** and **1**–**8** are given in the *Exper. Part.*

[2]) Despite the fact that (+)-nootkatone (**B**) is usually considered as the primary flavor-impact compound in grapefruit, the true flavoring importance of this ketone has recently been questioned [4].

quiterpene ketones **D–Q** *(Scheme 1)* for the first time in grapefruit juice flavor, together with the known representatives **B** and (+)-1,10-dihydronootkatone (**C**)[3]) [6] [7]. Among these ketones, *(+)-8,9-didehydronootkatone* (**E**) [2c] displays a particularly valuable grapefruit aroma similar to, but definitely stronger than that of (+)-nootkatone (**B**) itself.

Scheme 1. *Newly identified valencane-* (**D–J**) *and eudesmane-type* (**K–Q**) *ketones in grapefruit juice flavor* (The natural enantiomers are shown, with the possible exception of **O** (see *Section 4*))



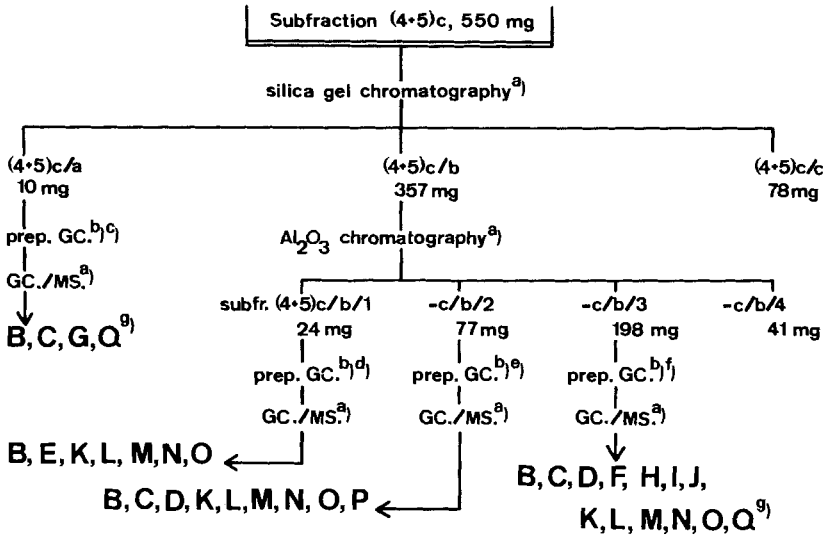
1. Preparation and fractionation of the volatile flavor of grapefruit juice. – The volatile flavor was prepared and preseparated by silica gel chromatography as previously described [1]. Distillation of the more polar constituents (Fr. 4+5, 2.33 g) gave three subfractions, (4+5)a–c, the least volatile of which ((4+5)c, b.p. > 70°/0.001 Torr, 0.550 g) was further separated along the lines of *Scheme 2* (see also *Exper. Part*). The individual sesquiterpene ketones **B–Q** thus isolated, together with many other components[4]), were characterized by their mass spectra (all compounds), ^{1}H-NMR spectra (**C**, **H**, **I**, **J**, **L**, **N**, **O**, **Q**), and t_R upon capillary GC. Their

[3]) (+)-1,10-Dihydronootkatone (**C**), a photoreduction product of (+)-nootkatone (**B**) [6], was formerly identified in grapefruit flavor by Dr. *A.F. Thomas* (*Firmenich SA*, Geneva, personal communication).

[4]) According to its ^{1}H-NMR spectrum, a compound isolated from these mixtures could be *paradisiol* (**R**, of 4-epi-intermedeol) [8], this agreeing with earlier findings [9]. Configurationally, **R** is ideally suited as a biosynthetic precursor for valencane-type sesquiterpenes [8], and its *in vivo* rearrangement to valencene (**S**) has been demonstrated to occur in grapefruit [9].

t_R relative to that of (+)-nootkatone (**B**, $t_R = 1.00$) are listed in the *Table*. As very small amounts of these natural ketones were available, specific rotation data could be obtained only for the relatively abundant representative **N** *(Sect. 3.4)*.

Scheme 2. *Isolation of sesquiterpene ketones* **B**-**Q** *from subfraction (4+5)c of the volatile flavor of grapefruit juice*



[a]) See *Exper. Part (Sect. 1)*. [b]) Preparative GC separations (2.5 × 0.004 m i.d. columns): *SO* = *silicone* oil 5% (*Embaphase, May & Baker, Ltd.*, Dagenham, England); *SP* = *SP-1000* 10% (*Carbowax 20 M* + substituted terephthalic acid; *Supelco, Inc.*, Bellefonte, Pennsylvania, USA). [c]) *SO*, 200–240°, combined with *SP*, 225–250°. [d]) *SO*, 185°. [e]) *SO*, 190°, combined with *SP*, 245°. [f]) *SO*, 190–250°, combined with *SP*, 210–250°. [g]) The other constituents of this mixture were mainly tertiary sesquiterpene alcohols.

Table. t_R *of ketones* **C**–**Q** *relative to (+)-nootkatone* (**B**). Conditions: 50 m × 0.3 mm glass capillary column, *UCON HB 50 5100*, 180°, isothermal

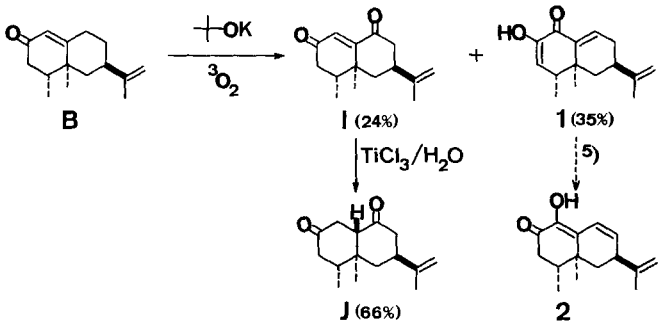
Ketone	t_R	Ketone	t_R	Ketone	t_R	Ketone	t_R
C	0.71	**N**	0.76	**K**	0.96	**F**	1.07
D	0.724	**Q**	0.78	**B**	1.00	**H**	1.59
P	0.727	**O**	0.86	**M**	1.04	**J**	2.15
G	0.73	**L**	0.87	**E**	1.05	**I**	2.19

2. Identification of valencane-type ketones *C–J*. – The known representatives **C**[3]) [6] [7], **D** [7], **E** [2c], **F** (α-vetivone) [7] [10], **G** [10b], and **H** [2c] were synthesized from (+)-nootkatone (**B**) according to literature procedures, and compared directly with the natural ketones isolated by GC *(Scheme 2)*.

The novel diketone **I** (m.p. 72°; $[\alpha]_D^{20} = +45°$ ($c = 1.29$, $CHCl_3$)) was obtained, together with hydroxyenone **1**[5]), by oxidation of (+)-nootkatone enolate with $^3O_2$ [11] *(Scheme 3)*.

[5]) Hydroxyenone **1** slowly isomerized to **2** during silica gel chromatography (see *Exper. Part*).

Scheme 3. *Preparation of* **I** *and* **J** via *oxidation of (+)-nootkatone* (**B**) *enolate*



The structure of **I** was ascertained by its ^{1}H-NMR spectrum[1]) showing expected signals at 1.05 (*d*, $J=6$, $H_3C-C(4)$); 1.11 (*s*, $H_3C-C(5)$); 1.51 (*t*, $J=13$, $H_{ax}-C(6)$); 1.78 (*s*, $H_3C-C(11)$); 2.11 ($d\times t$, $J_1=13$, $J_2=3$, $H_{eq}-C(6)$); 2.25 (*m*, $H_{ax}-C(4)$, collapsing to a $d\times d$, $J_1=10$, $J_2=7$, upon $H_3C-C(4)$ decoupling); 4.80 and 4.85 (*s* and narrow *m*, resp., $H_2C=C(11)$); 6.27 (*s*, $H-C(1)$).

Diketone **J** (m.p. 61°; $[\alpha]_D^{20}=+30°$ ($c=0.75$, $CHCl_3$)) was in turn prepared by conjugate reduction of **I** using $TiCl_3$ [12].

According to ^{1}H-NMR data[1]), this compound has an equatorial $H_3C-C(4)$ ($H_{ax}-C(4)$ at 1.94 ($d\times d$, $J_1=12$, $J_2=6$, after $H_3C-C(4)$ decoupling)), an equatorial isopropenyl group ($H-C(7)$ at 2.62 ($t\times t$, $J_1=13$, $J_2=4$)), and *trans*-fused rings ($H_3C-C(5)$ at 0.90 *vs.* 0.94 in the case of **C** [6] [7]).

While both synthetic diketones **I** and **J** proved to be identical with their natural counterparts (MS, ^{1}H-NMR), the formation of the former *via* oxidation of (+)-nootkatone (**B**) enolate *(Scheme 3)* might constitute a biomimetic process. If so, hydroxyenones **1** and/or **2** could occur naturally in grapefruit or other *Citrus species.*

3. Identification of eudesmane-type ketones *K–N* and *P–Q*[6]). – We identified (+)-α-cyperone (**P**) and (−)-10-epi-α-cyperone (**Q**) by direct comparison (MS: **P**, **Q**; ^{1}H-NMR: **Q**) with authentic samples prepared from (−)-2-carone [13] and (+)-dihydrocarvone [14], respectively. The less familiar ketones **K**-**N** (of which diastereoisomers **L**, **M** and **N** are novel compounds) were in turn synthesized from **P** and **Q**, using a regioselective 1,2-carbonyl transposition developed by *Nakai & Mimura* [15] and based on the *Shapiro* reaction [16] *(Scheme 4).* Contrary to published results [15a], however, this transposition reaction did not proceed stereoselectively when applied to (+)-α-cyperone (**P**), but afforded nearly equal amounts of ketones **K** and **L**. A better stereoselectivity was attained in the case of (−)-10-epi-α-cyperone (**Q**), from which the hydronaphthalenones **M** and **N** were produced in a 1:3 to 1:4 ratio probably reflecting the destabilizing effect of the axial isopropenyl group in **M**. The assignment of *cis* or *trans* ring fusion in the hydronaphthalenones **K**-**N** is based upon the ^{1}H-NMR data.

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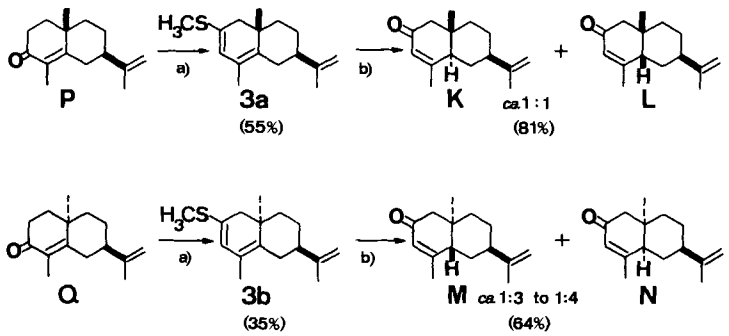
[6]) This group includes genuine eudesmane-type compounds (**K**, **P**), as well as 5- and/or 10-epi-eudesmane derivatives (**L**, **M**, **N**, **O**, **Q**).

Scheme 4. *Regioselective 1,2-carbonyl transposition of (+)-α-cyperone* (**P**) *and (−)-10-epi-α-cyperone* (**Q**) *according to* Mimura & Nakai [15]

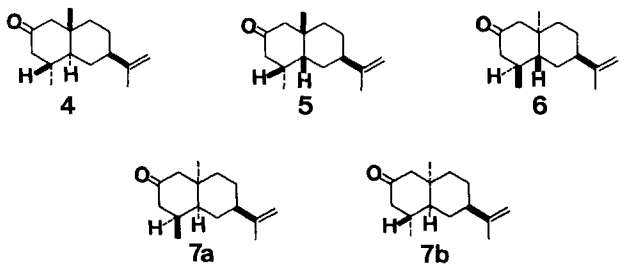


[a]) $TsNHNH_2$; BuLi/$(CH_3)_2NCH_2CH_2N(CH_3)_2$, −78°; CH_3SSCH_3, −78–0°; BuLi, −78°; room temp., then H_2O; [b]) $HgCl_2/H_2O$.

3.1. Ketone **K** ($[\alpha]_D^{20} = +109°$ ($c = 0.45$, $CHCl_3$)). According to its ^{1}H-NMR spectrum[1]), this diastereoisomer has an equatorial isopropenyl group (H–C(7) at 2.07 ppm, $t \times t$, $J_1 = 12$, $J_2 = 3.5$ Hz) and *trans*-fused rings, the latter point being demonstrated by the appearance of H–C(5) at 2.40 ppm as a $d \times m$ with $J_1 = 13$ Hz (ax,ax), a coupling pattern clearly incompatible with the alternative *cis*-structure **L**. Confirming this assignment, H_3C–C(10) appears at 0.80[7]) in the spectrum of perhydronaphthalenone **4** resulting from conjugate reduction of **K**.

3.2. Ketone **L** (m.p. 38°; $[\alpha]_D^{20} = -61°$ ($c = 0.87$, $CHCl_3$)). In the ^{1}H-NMR spectrum[1]) of this *cis*-hydronaphthalenone ('steroid-like' conformation with equatorial isopropenyl group), H–C(5) should appear as a $t \times t$ with estimated $J_1 = 3$–4 (eq,ax and eq,eq couplings to $H_2C(6)$), and $J_2 = 1$–2 Hz (allylic coupling to H–C(3) and long-range 'W' coupling to H_{eq}–C(9)). Such a signal indeed occurs at 2.34 ppm as a narrow, unresolved *m* having adequate $W_{1/2}$ (≈ 10 Hz). The *cis* ring fusion in **L** is further indicated by the H_3C–C(10) *s* at 1.13 ppm[7]) in the spectrum of the derived perhydronaphthalenone **5**.

3.3. Ketone **M** ($[\alpha]_D^{20} = -70°$ ($c = 0.64$, $CHCl_3$)). The whole configuration of this diastereoisomer can be directly deduced from the ^{1}H-NMR signal of H_{ax}–C(6), which appears at 1.56 ppm as a $d \times t$ arising from geminal ($J = 14$), ax,ax ($J = 14$), and ax,eq ($J = 5$ Hz) couplings. This signal, collapsing to a *d* ($J \approx 15$ Hz) after H–C(5) and H–C(7) double decoupling, is fully specific for the *trans*-hydronaphthalenone structure **M** with axial isopropenyl group. This assignment further agrees with the position at 0.83 ppm[7]) of the H_3C–C(10) *s* in the spectrum of the related perhydronaphthalenone **6**.



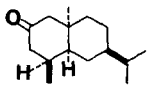
[7]) In *cis/trans*-pairs of angularly methylated hydronaphthalenones, usually $\delta(CH_3; cis) > \delta(CH_3; trans)$. This holds for 4a-methyl-perhydronaphthalen-1-one ($\delta(CH_3$; *cis/trans*$) = 1.05/0.80$) [17], 4a-methyl-perhydronaphthalen-2-one (1.19/1.04) [18], 8a-methyl-perhydronaphthalen-1-one (1.18/1.08) [19], and 8a-methyl-perhydronaphthalen-2-one (0.97/0.79) [20] (a case directly relevant to the present work).

3.4. Ketone **N** ($[\alpha]_D^{20} = +128°$ ($c = 0.60$, $CHCl_3$)). As in the case of ketone **M**, the whole configuration of this diastereoisomer is directly deducible from the ^{1}H-NMR signal of H_{ax}–C(6). Indeed, this proton appears at 1.16 ppm as a *qa* with $J = 13$ Hz (geminal coupling, ax,ax couplings to H–C(5) and H–C(7)), and such a multiplicity can be reconciled only with the *cis*-hydronaphthalenone structure **N** (as stable conformer with equatorial isopropenyl group). This assignment is further confirmed by the H_3C–C(10) signals appearing at 0.95[7]) and 1.05 ppm[7]) in the spectra of the respective perhydronaphthalenones **7a** and **7b**, both produced by conjugate reduction of **N**.

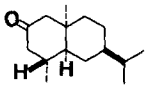
Synthetic ketones **K**–**N** proved to be identical with their natural counterparts (MS, t_R, ^{1}H-NMR for **L** and **N**). Moreover, the specific rotation ($[\alpha]_D^{20} = +133°$ ($c = 0.15$, $CHCl_3$)) of natural **N**, which for once could be measured[8]), agrees well with that of synthetic material (+ 128°). This confirms the isopropenyl group to be β-oriented ((7*R*)-configuration) in natural **N**, as generally observed in eudesmane-type sesquiterpenes. We consequently also assign the (7*R*)-configuration to the other natural ketones (**K**–**M**) of this series, despite the fact that no specific rotation data are available for them. Interestingly enough, ketone **K** represents an alternative structure previously proposed for (+)-nootkatone (**B**) [2a] [2c].

4. Ketone *O* (m.p. 92°; $[\alpha]_D^{20} = +83°$ ($c = 0.82$, $CHCl_3$)). – *cis*-Hydronaphthalenone **O** resulted from acid-catalyzed isomerization of either ketones **N** or **M**, the latter apparently undergoing conversion to the more stable *cis*-isomer **N** prior to double-bond rearrangement (see *Exper. Part*). The planar structure of **O** was ascertained by its ^{1}H-NMR spectrum, and its *cis* ring fusion by the ^{1}H-NMR data of its perhydronaphthalenone derivatives **8a** and **8b**, obtained as *ca.* 1:1 mixture by successive lithium-ammonia reduction and hydrogenation (Pt/H_2) of **O**.

The four methyl signals of **O** appear at 0.97 (H_3C–C(10)), 1.69 and 1.71 ($2\,H_3C$–C(*11*)), and 1.98 ppm (H_3C–C(4)), and H–C(3) at 5.83 ppm[1]). In the ^{1}H-NMR spectrum of **8a**, H–C(4) gives rise to a $d \times t$ due to one ax,ax ($J = 12$ Hz) and two ax,eq ($J = 5$ Hz) couplings, a result consistent only with the *cis* structure **8a**. The *cis* ring fusion in ketone **O** is further confirmed by the H_3C–C(10) signals appearing at 0.92[7]) and 1.03 ppm[7]) for **8a** and **8b**, respectively.



8a



8b

Synthetic and natural ketone **O** had identical t_R, mass and ^{1}H-NMR spectra. However, the absolute configuration of the natural representative remains unsettled, as no specific rotation data are available for this compound which can be related to either **L** or **N** in grapefruit.

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[8]) Ketone **N** is the major diastereoisomer occurring in volatile grapefruit juice flavor, which contains 0.05, 0.06, 0.07, and 0.29% of ketones **K**, **L**, **M**, and **N**, respectively.

Experimental Part

General remarks. See [1]. The m.p. are uncorrected. Because all mass spectra were obtained by GC/MS coupling, the relative peak intensities indicated may differ somewhat from those measured under ordinary, static conditions.

1. Fractionation of volatile grapefruit flavor *(Scheme 2).* – Fractions 4 and 5 (total 2.33 g) resulting from silica gel chromatography of crude volatile grapefruit flavor [1] were combined and distilled to afford subfractions (4+5)*a* (b.p. 70–88°/10 Torr, 1.51 g), (4+5)b (b.p. 50–70°/0.001 Torr, 0.26 g), and (4+5)c (b.p. > 70°/0.001 Torr, 0.55 g). Chromatography of the latter on silica gel (11 g) using successively hexane, Et_2O, and Et_2O/MeOH 85:15 gave further subfractions (4+5)c/a (10 mg), (4+5)c/b (357 mg), and (4+5)c/c (78 mg). While the first of these could be examined directly by GC, the last one was discarded, and the major subfraction (4+5)c/b was rechromatographed on alumina (13 g, activity II). Successive elution with hexane, Et_2O, and MeOH yielded the ultimate subfractions (4+5)c/b/1 to −4, which were then subjected to semiprep. GC. Final identification of ketones **B**–**Q**, as well as proper monitoring of the whole separation process, were efficiently ensured by GC/MS coupling (50 m × 0.3 mm glass capillary column coated with *UCON HB 5100*, temp. programmed from 140 up to 180° at +2.5°/min).

2. Valencane-type ketones *C–J*. – 2.1. *MS of ketones* **C**–**H**. *(+)-1,10-Dihydronootkatone* (**C**)[3] [6] [7]: 220 (25, M^+, $C_{15}H_{24}O$), 205 (13), 135 (43), 107 (100), 93 (66), 82 (48), 69 (46), 67 (48), 55 (45), 41 (73).

(−)-β,γ-Nootkatone (**D**) [7]: 218 (2, M^+, $C_{15}H_{22}O$), 203 (9), 177 (28), 133 (45), 107 (43), 105 (100), 93 (56), 91 (63), 80 (60), 41 (63).

(+)-8,9-Didehydronootkatone (**E**) [2c]: 216 (74, M^+, $C_{15}H_{20}O$), 201 (9), 174 (45), 159 (59), 145 (77), 131 (100), 105 (39), 91 (70), 77 (43), 41 (75), 39 (47).

(+)-α-Vetivone (**F**) [7] [10]: 218 (44, M^+, $C_{15}H_{22}O$), 203 (20), 185 (100), 147 (37), 121 (44), 105 (37), 91 (45), 55 (39), 41 (64).

(+)-1,10-Dihydro-α-vetivone (**G**) [10b]: 220 (45, M^+, $C_{15}H_{24}O$), 205 (6), 135 (62), 107 (52), 93 (50), 83 (100), 69 (40), 67 (48), 55 (60), 41 (69).

(+)-8,9-Didehydro-α-vetivone (**H**) [2c]: 216 (63, M^+, $C_{15}H_{20}O$), 201 (2), 174 (32), 159 (100), 131 (30), 119 (30), 91 (35), 41 (34).

2.2. *(+)-(3S,4aS,5R)-3-Isopropenyl-4a,5-dimethyl-2,3,4,4a,5,6-hexahydro-1,7-naphthoquinone* (**I**), *(−)-(4R,4aS,6R)-2-hydroxy-6-isopropenyl-4,4a-dimethyl-4a,5,6,7-tetrahydro-1(4H)-naphthalenone* (**1**) *and (+)-(4R,4aS,6S)-1-hydroxy-6-isopropenyl-4,4a-dimethyl-4,4a,5,6-tetrahydro-2(3H)-naphthalenone* (**2**). A mixture of K*t*BuO (11.81 g, 105 mmol), anhydrous *t*-BuOH (115 ml) and 1,2-dimethoxyethane (DME, 192 ml) was stirred for 10 min at −20° under O_2, when (+)-nootkatone (**B**, 10.00 g, 45.8 mmol) in DME (10 ml) was added dropwise to the solution within 20 min [11]. After 1½ h further stirring with simultaneous warming to room temp. (total O_2 uptake about 1 l), the mixture was diluted with H_2O (400 ml) and extracted twice with Et_2O. Usual treatment of the combined org. layers (washing to neutrality, drying over $MgSO_4$, concentration) afforded 7.53 g of crude product containing 30% of unreacted **B**, 38% of **1**, and 27% of **I** (conversion yield 24%; capillary GC, *UCON HB 5100*, 180°, 50 m × 0.3 mm glass column). Chromatography of this mixture on silica gel (226 g) gave pure **1** (1.05 g, eluted with hexane/EtOAc 94:6 to 90:10), **B** (2.22 g, hexane/EtOAc 90:10 to 80:20), **I** (2.60 g, hexane/EtOAc 80:20 to 75:25), and miscellaneous intermediate fractions. During this separation, some **2** was produced[9]) by isomerization of **1**, thus requiring **I** to be further purified by successive chromatography on alumina (25 parts, activity III, hexane/Et_2O 9:1 to 1:1) and recrystallization from pentane.

Data of **I**. M.p. 71–72.5°, $[\alpha]_D^{20} = +45.7°$ ($c = 1.29$, $CHCl_3$). – IR ($CHCl_3$): 1690, 1675, 1660, 1235. – ^{1}H-NMR: see *General Part.* – MS: 232 (40, M^+, $C_{15}H_{20}O_2$), 148 (92), 147 (98), 135 (100), 93 (82), 91 (85), 79 (81), 77 (85), 66 (96), 41 (80).

Data of **1**. M.p. 88.5–89.5°, $[\alpha]_D^{20} = -37°$ ($c = 1.27$, $CHCl_3$). – IR ($CHCl_3$): 1225, 1615, 1650, 1660, 1415, 1280, 3450. – ^{1}H-NMR[1]): 1.07 (*s*, H_3C–C(5)); 1.12 (*d*, $J = 7.5$, H_3C–C(4)); 1.40 (*t*, $J = 12.5$,

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9) Apparently in the form of dimeric or polymeric material, m.p. 166–167.5°, which underwent thermal depolymerization to **2** upon GC (*silicone* oil 5%, 260°, 5 × 0.004 m column).

H_{ax}–C(6)); 1.77 (*s*, H_3C–C(11)); 1.91 (*d*×*t*, $J_1 = 12.5$, $J_2 = 2$, H_{eq}–C(6)); 2.10 (*d*×*d*×*d*, $J_1 = 18$, $J_2 = 11$, $J_3 = 2$, H_{ax}–C(8)); 2.30 (*ca. t*×*t*, $J_1 \approx 12$, $J_2 \approx 5$, H–C(7)); 2.39 (*d*×*d*×*t*, $J_1 = 18$, $J_2 = 2$, $J_3 = 5$, H_{eq}–C(8)); 2.59 (*d*×*qa*, $J_1 = 2.5$, $J_2 = 7.5$, H–C(4)); 4.78, 4.82 (*s* and narrow *m*, resp., H_2C=C(11)); 5.77 (*d*, $J = 2.5$, H–C(3)); 6.11 (*s*, HO–C(2)); 6.90 (*d*×*d*, $J_1 = 5$, $J_2 = 2$, H–C(9)). – MS: 232 (7, M^+, $C_{15}H_{20}O_2$), 189 (12), 164 (100), 93 (12), 91 (13), 69 (29), 41 (15).

Data of **2** (sample isolated by semi-prep. GC (s. *footnote 9*). M.p. 65–67°, $[\alpha]_D^{20} = +193.4°$ ($c = 1.22$, $CHCl_3$). – ^{1}H-NMR[1]): 0.99 (*d*, $J = 7.5$, H_3C–C(4)); 1.06 (*s*, H_3C–C(5)); 1.28 (*t*, $J = 12.5$, H_{ax}–C(6)); 1.75 (*s*, H_3C–C(11)); 1.95 (*d*×*d*×*d*, $J_1 = 12.5$, $J_2 = 5$, $J_3 \approx 1.5$, H_{eq}–C(6)); 2.06 (*d*×*d*×*qa*, $J_1 = 13$, $J_2 = 6$, $J_3 = 7.5$, H–C(4)); 2.47 (*m*, 2 H–C(3)); 3.03 (*d*×*m*, $J_1 = 13$, H–C(7)); 4.83 (narrow *m*, H_2C=C(11)); 6.03 (*d*×*m*, $J_1 = 10$, H–C(8)); 6.72 (*d*×*d*, $J_1 = 10$, $J_2 = 3.5$, H–C(9)). – MS: 232 (100, M^+, $C_{15}H_{20}O_2$), 217 (22), 203 (46), 161 (42), 147 (30), 105 (36), 91 (54), 77 (34), 41 (40).

2.3. *(+)-(3S,4aS,5R,8aS)-3-Isopropenyl-4a,5-dimethyl-perhydro-1,7-naphthoquinone* (**J**). $TiCl_3$ (262 mg, 1.70 mmol, 15% aq. solution) was quickly added at 20° under N_2 to a stirred solution of **I** (194 mg, 0.83 mmol) in acetone (16 ml) [12]. After 12 min further stirring at 20°, the mixture was poured into sat. NaCl solution (150 ml) and extracted twice with Et_2O. The crude product (219 mg) resulting from usual work-up was chromatographed on silica gel (9 g) in the presence of hexane/Et_2O 99:1 to 65:35 as eluent, affording 129 mg (66%) of **J** (eluted with hexane/Et_2O 85:15 to 75:25). Further purified by recrystallization in pentane/Et_2O, **J** had m.p. 60–61°, $[\alpha]_D^{20} = +30.6°$ ($c = 0.75$, $CHCl_3$). – IR ($CHCl_3$): 1705, 1235, 1255, 1440, 1640. – ^{1}H-NMR[1]): 0.90 (*s*, H_3C–C(5)); 0.97 (*d*, $J = 6.5$, H_3C–C(4)); 1.45 (*t*, $J = 13$, H_{ax}–C(6)); 1.76 (*s*, H_3C–C(11)); 1.94 (*d*×*d*×*qa*, $J_1 = 12$, $J_2 = 6$, $J_3 = 6.5$, H–C(4)); 2.06 (*d*×*m*, $J_1 = 13$, H_{eq}–C(6)); 2.15–2.54 (*m*, 7 H, 2 H–C(1), 2 H–C(3), 2 H–C(8), H–C(10)); 2.62 (*t*×*t*, $J_1 = 13$, $J_2 = 4$, H–C(7)); 4.79, 4.82 (*s* and narrow *m*, resp., H_2C=C(11)). – MS: 234 (49, M^+, $C_{15}H_{22}O_2$), 151 (100), 123 (40), 121 (40), 107 (40), 95 (56), 82 (47), 69 (65), 68 (86), 67 (75), 55 (53), 41 (62).

3. Eudesmane-type ketones *K*–*Q*[6]). – 3.1. *(+)-(4aR,6R,8aS)- and (−)-)4aS,6R,8aS)-6-Isopropenyl-4,8a-dimethyl-4a,5,6,7,8,8a-hexahydro-2(1H)-naphthalenone* (**K** *and* **L**) [15]. A mixture of (+)-α-cyperone [13] (**P**, 4.61 g, 21 mmol; $[\alpha]_D^{20} = +76°$ ($c = 0.33$, $CHCl_3$)) and tosylhydrazine (5.10 g, 27 mmol) in AcOH (31.5 ml) was stirred for 2 h at 40° under N_2 and then concentrated to dryness at 10 Torr (in the presence of toluene to ensure total, azeotropic removal of AcOH). Recrystallization of the residue from MeOH gave 6.05 g (74%) of (+)-α-cyperone tosylhydrazone, m.p. 175–176° to 183–184° (*E*/*Z* isomerism).

BuLi (31.5 mmol, 20.2 ml of 10% hexane solution) was added dropwise during 30 min at −78° under N_2 to a stirred mixture of (+)-α-cyperone tosylhydrazone (6.05 g, 15 mmol), anh. tetrahydrofuran (THF, 180 ml) and *N,N,N′,N′*-tetramethylenediamine (TMEDA, 90 ml). After 10 min further stirring at −30°, dimethyl disulfide (1.34 ml, 15 mmol) was added during 5 min at −78°. The mixture was allowed to warm to 0°, kept for 15–20 min at this temp., and cooled again to −78°, when BuLi (14.9 mmol, 9.55 ml of 10% hexane solution) was added within 13 min. After 2 h stirring at room temp. (N_2 evolution), the mixture was poured at 0° into 10% NH_4Cl solution and extracted with Et_2O (3 times). The combined org. layers, carefully washed to neutrality and worked up as usual, afforded 4.40 g of crude *3-isopropenyl-5,8a-dimethyl-7-methylthio-1,2,3,4,8,8a-hexahydronaphthalene* (**3a**). Distillation at 99°/0.01 Torr gave 2.04 g (55%). – IR: 890, 1435, 1450, 1370, 1635, 1350, 1570. – ^{1}H-NMR: 0.91 (*s*, 3 H); 1.72 (*d*, $J = 2$, 3 H); 1.76 (*s*, 3 H); 2.28 (*s*, 3 H); 2.60 (*d*×*t*, $J_1 = 14$, $J_2 = 2.5$, 1 H); 4.74 (narrow *m*, 2 H); 5.39 (*d*, $J = 2.5$, 1 H).

A mixture of **3a** (2.04 g, 8.2 mmol), CH_3CN (39 ml) and H_2O (13 ml) was added dropwise during 10 min at 20° under N_2 to a stirred solution of $HgCl_2$ (6.69 g, 24.6 mmol) in CH_3CN (37 ml) and H_2O (12 ml) [21]. After 1½ h further stirring at 60°, the mixture was extracted with Et_2O (3 times) and the combined org. layers washed with sat. $NaHCO_3$ solution (4 times) and H_2O (3 times). The pentane-soluble part (1.57 g) of the resulting crude extract consisted essentially of a mixture of **K** (48%) and **L** (45%) (total yield 81%; capillary GC, *UCON HB 50 5100*, 180°). These ketones, separated by chromatography on silica gel/$AgNO_3$ 9:1 (78.5 g) with hexane/Et_2O 98:2 to 70:30, were finally purified by semiprep. GC (*SP-1000* 10%, 250°, 2.5 × 0.004 m column).

Data of **K**: $[\alpha]_D^{20} = +109°$ ($c = 0.45$, $CHCl_3$). – IR: 1655, 1370, 1430, 1610, 880. – ^{1}H-NMR[1]): 0.90 (*s*, H_3C–C(10)); 1.32 (*qa*, $J = 13$, H_{ax}–C(6)); 1.40–1.70 (*m*, 4 H, 2 H–C(8), 2 H–C(9)); 1.77 (*s*, H_3C–C(11)); 1.91 (narrow *m*, H_3C–C(4)); 2.07 (*t*×*t*, $J_1 = 12$, $J_2 = 3.5$, H–C(7)); 2.20, 2.29 (*AB*, $J = 16$,

2 H–C(1)); 2.40 ($d\times m$, $J_1 = 13$, H–C(5)); 4.76 (narrow *m*, H_2C=C(11)); 5.90 (narrow *m*, H–C(3)). – MS: 218 (11, M^+, $C_{15}H_{22}O$), 203 (3), 176 (26), 133 (21), 107 (16), 95 (100), 93 (20), 69 (60), 67 (34), 41 (35).

Data of **L**. M.p. 38°, $[\alpha]_D^{20} = -61°$ ($c = 0.87$, $CHCl_3$). – IR: 1660, 1375, 1430, 885, 1290, 1610. – ^{1}H-NMR[1]): 1.11 (*s*, H_3C–C(10)); 1.28 (*m*, 1 H); 1.58 (*m*, 3 H); 1.74 (*s*, H_3C–C(11)); 1.85 (narrow *m*, 3 H); 1.95 (*s*, H_3C–C(4)); 2.22, 2.32 (*AB*, $J = 16$, 2 H–C(1)); 2.34 (narrow *m*, $W_{1/2} \approx 10$, H–C(5)); 4.75, 4.79 (*s* and narrow *m*, resp., H_2C=C(11)); 5.93 (br. *s*, H–C(3)). – MS: 218 (23, M^+, $C_{15}H_{22}O$), 203 (9), 123 (90), 107 (43), 95 (100), 79 (51), 69 (50), 67 (58), 41 (63).

3.2. *(–)-(4a*S*,6*R*,8a*R*)- and (+)-(4a*R*,6*R*,8a*R*)-6-Isopropenyl-4,8a-dimethyl-4a,5,6,7,8,8a-hexahydro-2(1*H*)naphthalenone* (**M** *and* **N**). The above 1,2-carbonyl transposition sequence [15] (s. *3.1*) was applied to (–)-10-epi-α-cyperone [14] (**Q**; $[\alpha]_D^{20} = -180.5°$ ($c = 1.12$, $CHCl_3$)) *via* the corresponding tosylhydrazone, m.p. 156–157° (yield 88%), and the sulfide **3b**, b.p. 100°/0.01 Torr (35%). – IR: 1450, 1435, 890, 1635, 1365, 1570. – ^{1}H-NMR: 0.94 (*s*, 3 H); 1.70 (*s*, 3 H); 1.74 (*d*, $J = 2$, 3 H); 2.28 (*s*, 3 H); 2.67 ($d\times t$, $J_1 = 16$, $J_2 = 2$, 1 H); 4.77, 4.80 (2 br. *s*, 2 H); 5.37 (*d*, $J = 2.5$, 1 H).

Hydrolytic cleavage [21] of **3b** produced a mixture of **M** and **N** (1:3 to 1:4, 64%), which were isolated by silica gel/$AgNO_3$ 9:1 chromatography and semiprep. GC as described for **K**/**L**.

Data of **M**: $[\alpha]_D^{20} = -70°$ ($c = 0.64$, $CHCl_3$). – IR: 1655, 1430, 1370, 1250, 1605, 885. – ^{1}H-NMR[1]): 0.94 (*s*, H_3C–C(10)); 1.28 ($d\times t$, $J_1 = 13$, $J_2 = 3.5$, H_{eq}–C(9)); 1.56 ($d\times t$, $J_1 = 5$, $J_2 = 14$, H_{ax}–C(6), partially obscured by another 1 H signal); 1.78 (*s*, H_3C–C(11)); 1.90 (narrow *m*, H_3C–C(4)); 2.20 (*m*, 2 H–C(1)); 2.50 (*m*, H–C(5) and H–C(7)); 4.88, 4.99 (2 narrow *m*, H_2C=C(11)); 5.88 (narrow *m*, H–C(3)). – MS: 218 (19, M^+, $C_{15}H_{22}O$), 203 (5), 176 (100), 175 (100), 161 (43), 147 (45), 95 (95), 93 (45), 91 (41), 69 (77), 67 (67), 55 (44), 41 (86).

Data of **N**: $[\alpha]_D^{20} = +128°$ ($c = 0.60$, $CHCl_3$). – IR: 1650, 1620, 1370, 1240, 1435, 885. – ^{1}H-NMR[1]): 0.98 (*s*, H_3C–C(10)); 1.16 (*qa*, $J = 13$, H_{ax}–C(6)); 1.73 (*s*, H_3C–C(11)); 1,83, 2.67 (*AB*, $J = 17$, 2 H–C(1)); 1.97 (*d*, $J = 2$, H_3C–C(4)); 4.71, 4.73 (*s* and narrow *m*, resp., H_2C=C(11)); 5.82 (*s*, H–C(3)). – MS: 218 (21, M^+, $C_{15}H_{22}O$), 203 (13), 123 (64), 107 (26), 95 (100), 79 (32), 69 (31), 67 (44), 41 (48).

3.3. *Li/NH_3 reduction of* **K**–**N** *to* **4**–**7**. General procedure [22]: liquid NH_3 (30–35 ml, predried by successive addition of some Li and distillation) was placed at –50° in a 3-necked flask. A solution of any of the ketones **K**–**N** (218 mg, 1.0 mmol) and *t*-BuOH (86.7 mg, 1.17 mmol) in dry Et_2O (10 ml) was then quickly added at –50° with stirring, followed by small pieces of Li (43 mg, 6.2 mmol). After further stirring at –50° until the blue color had disappeared (20–30 min), an excess of solid NH_4Cl was added to the solution. NH_3 was allowed to evaporate, Et_2O and sat. NaCl solution were added, the mixture was extracted with Et_2O (twice) and the combined Et_2O layers washed with sat. NaCl solution (3 times) and H_2O (once). The crude product resulting from usual work-up (yield of **4**–**7**: 80–100% by capillary GC) was finally purified by chromatography on silica gel/$AgNO_3$ 9:1, microdistillation, and/or semiprep. GC (*SP-1000* 10%, 250°, 2.5 × 0.004 m column).

*(4*R*,4a*S*,6*R*,8a*S*)-6-Isopropenyl-4,8a-dimethyl-perhydronaphthalen-2-one* (**4**; *from reduction of* **K**): ^{1}H-NMR[1]): 0.80 (*s*, H_3C–C(10)); 0.98 (*d*, $J = 7$, H_3C–C(4)); 1.73 (after H_3C–C(4) decoupling: $d\times t$, $J_1 = 5$, $J_2 = 12$, H–C(4)); 1.75 (*s*, H_3C–C(11)); 2.11 ($d\times d$, $J_1 = 13$, $J_2 = 2$, H–C(1)); 2.17 (*d*, $J = 13$, H–C(1)); 2.37 ($d\times d\times d$, $J_1 = 14$, $J_2 = 5$, $J_3 = 2$, H_{eq}–C(3)); 4.72 (br. *s*, H_2C=C(11)). – MS: 220 (100, M^+, $C_{15}H_{24}O$), 205 (37), 177 (33), 162 (37), 137 (51), 123 (45), 107 (81), 95 (86), 93 (60), 82 (68), 81 (67), 69 (73), 55 (57), 41 (67).

*(4*R*,4a*R*,6*R*,8a*S*)-6-Isopropenyl-4,8a-dimethyl-perhydronaphthalen-2-one* (**5**; *from reduction of* **L**): ^{1}H-NMR[1]): 1.03 (*d*, $J = 6$, H_3C–C(4)); 1.13 (*s*, H_3C–C(10)); 1.72 (*s*, H_3C–C(11)); 2.06 ($d\times d$, $J_1 = 13$, $J_2 = 3$, 1 H); 2.14 (*d*, $J = 12$, 1 H); 2.30 ($d\times t$, $J_1 = 12$, $J_2 = 3$, 1 H); 2.32 (*d*, $J = 13$, 1 H); 4.70 (br. *s*, H_2C=C(11)). – MS: 220 (18, M^+, $C_{15}H_{24}O$), 205 (75), 162 (22), 135 (48), 123 (100), 107 (55), 93 (58), 82 (47), 67 (51), 55 (63), 41 (73).

*(4*S*,4a*R*,6*R*,8a*R*)-6-Isopropenyl-4,8a-dimethyl-perhydronaphthalen-2-one* (**6**; *from reduction of* **M**): ^{1}H-NMR[1]): 0.83 (*s*, H_3C–C(10)); 0.99 (*d*, $J = 7$, H_3C–C(4)); 1.19 ($d\times t$, $J_1 = 13$, $J_2 = 3$, 1 H); 1.29 ($d\times t$, $J_1 = 5$, $J_2 = 13$, 1 H); 1.76 (*s*, H_3C–C(11)); 1.98 (*t*, $J = 13$, H_{ax}–C(3)); 4.86, 4.96 (2 *s*, H_2C=C(11)). – MS: 220 (11, M^+, $C_{15}H_{24}O$), 205 (10), 162 (10), 137 (49), 123 (25), 107 (37), 95 (34), 82 (100), 69 (44), 55 (43), 41 (47).

(4S,4aS,6R,8aR)- and (4R,4aS,6R,8aR)-6-Isopropenyl-4,8a-dimethyl-perhydronaphthalen-2-one (**7a** *and* **7b**; *formed in a 3:1 ratio by reduction of* **N**). **7a** *(major):* ^{1}H-NMR[1]): 0.95 (*s*, $H_3C-C(10)$); 0.99 (*d*, $J=7$, $H_3C-C(4)$); 1.27 (*qa*, $J=12$, $H_{ax}-C(6)$); 1.76 (narrow *m*, $H_3C-C(11)$); 1.95 ($t\times t$, $J_1=11.5$, $J_2=3.5$, $H-C(7)$); 2.04–2.16 (*m*, 2 H–C(3)); 2.38 (after $H_3C-C(4)$ decoupling: $d\times t$, $J_1=12$, $J_2=4.5$, $H-C(4)$); 2.66 (*d*, $J=14$, $H_{ax}-C(1)$); 4.73 (br. *s*, $H_2C=C(11)$). – MS: 220 (19, M^+, $C_{15}H_{24}O$), 205 (56), 162 (42), 135 (34), 121 (46), 107 (81), 93 (93), 81 (64), 69 (79), 55 (85), 41 (100).

Data of **7b** *(minor):* ^{1}H-NMR[1]): 1.05 (*s*, $H_3C-C(10)$); 1.17 (*d*, $J=7$, $H_3C-C(4)$); 1.73 ($d\times t$, $J_1=13$, $J_2=1.5$, $H_{eq}-C(1)$); 1.76 (*s*, $H_3C-C(11)$); 1.98 ($t\times t$, $J_1=11$, $J_2=3.5$, $H-C(7)$); 2.07 ($d\times t$, $J_1=14$, $J_2\approx 2$, $H_{eq}-C(3)$); 2.12 (after $H_3C-C(4)$ decoupling: narrow *m*, $W_{1/2}=7$, $H-C(4)$); 2.58 ($d\times d$, $J_1=14$, $J_2=7$, $H_{ax}-C(3)$); 2.67 (*d*, $J=13$, $H_{ax}-C(1)$); 4.72 (br. *s*, $H_2C=C(11)$). – MS: 220 (4, M^+, $C_{15}H_{24}O$), 205 (23), 162 (20), 135 (22), 123 (100), 107 (35), 93 (41), 81 (36), 67 (41), 55 (47), 41 (51).

3.4. *(+)-(4aR,8aR)-6-Isopropylidene-4,8a-dimethyl-4a,5,6,7,8,8a-hexahydro-2(1H)-naphthalenone* (**O**). a) Hydronaphthalenone **N** (300 mg, 1.37 mmol; $[\alpha]_D^{20}=+128°$ ($c=0.60$, $CHCl_3$)) and *p*-toluenesulfonic acid monohydrate (TsOH, 15 mg, 0.07 mmol) were stirred in toluene (3 ml) at 85° under N_2. After 1 h, a further portion of TsOH (15 mg) was added and the mixture stirred again at 85°, until capillary GC (*UCON HB 50 5100*, 180°) indicated that 70% of **N** had isomerized to **O** (total reaction time: 3 h). The solution was then extracted with Et_2O (3 times), washed with sat. $NaHCO_3$ solution and H_2O, and the crude product (381 mg) resulting from usual work-up chromatographed on 50 parts of silica gel/$AgNO_3$ 9:1. Elution with hexane/Et_2O 9:1 to 7:3 gave 160 mg (53%) of **O**, m.p. 92–92.5° (pentane), $[\alpha]_D^{20}=+83°$ ($c=0.82$, $CHCl_3$). – IR: 1655, 1375, 1245, 1435, 890. – ^{1}H-NMR[1]): 0.97 (*s*, $H_3C-C(10)$); 1.32 ($d\times t$, $J_1=4$, $J_2=13.5$, $H_{ax}-C(9)$); 1.54 ($d\times t$, $J_1=13.5$, $J_2=4$, $H_{eq}-C(9)$); 1.69 (*s*, $H_3C-C(11)$); 1.71 (*d*, $J\approx 2$, $H_3C-C(11)$); 1.90, 2.79 (2 *d*, $J=17$, 2 H–C(1)); 1.98 (*d*, $J\approx 1.5$, $H_3C-C(4)$); 2.53 ($d\times d\times t$, $J_1=14$, $J_2\approx 4$, $J_3=4$, $H_{eq}-C(8)$); 5.83 (*s*, H–C(3)). – MS: 218 (16, M^+, $C_{15}H_{22}O$), 203 (7), 160 (11), 147 (15), 135 (24), 123 (100), 107 (10), 91 (12), 79 (14), 67 (13), 55 (13), 41 (22).

b) When treated under the same acidic conditions as above, *trans*-compound **M** underwent isomerization to a mixture of **O** and **N** (*ca.* 6:4) suggesting the **M** → **N** → **O** pathway for this reaction.

3.5. *Consecutive Li/NH_3 reduction and catalytic hydrogenation of* **O** *to* **8a** *and* **8b**. When carried out as described in *Sect. 3.3*, Li/NH_3 reduction of **O** and subsequent chromatographic separation of the resulting product afforded nearly equal amounts of two epimeric perhydronaphthalenones **I** and **II** (t_R (I) < t_R (II), capillary GC, *UCON*, 180°).

Data of Epimer **I**: ^{1}H-NMR[1]): 0.92 ($H_3C-C(10)$); 1.03 (*d*, $J=6.5$, $H_3C-C(4)$); 1.27–1.47 (*m*, 3 H); 1.69 (br. *s*, 2 $H_3C-C(11)$); 1.69–1.91 (*m*, 2 H); 1.76 (*d*, $J=14$, H–C(1)); 2.11–2.19 (*m*, 2 H–C(3)); 2.36 (*m*, H–C(4)); 2.55 ($d\times d\times t$, $J_1=14$, $J_2\approx 2$, $J_3=3$, $H_{eq}-C(8)$); 2.66 ($d\times t$, $J_1=14$, $J_2=3$, $H_{eq}-C(6)$); 2.81 (*d*, $J=14$, H–C(1)).

Data of Epimer **II**: ^{1}H-NMR[1]): 1.02 (*d*, $J=6.5$, $H_3C-C(4)$); 1.19 (*s*, $H_3C-C(10)$); 1.38 ($d\times t$, $J_1=4.5$, $J_2=13$, $H_{ax}-C(9)$); 1.63, 1.68 (2 narrow *m*, 2 $H_3C-C(11)$); 1.83–2.00 (*m*, 2 H); 2.04 (*d*, $J=13.5$, H–C(1)); 2.06 (*t*, $J=13.5$, $H_{ax}-C(3)$); 2.17 ($d\times m$, $J_1=14$, $H_{ax}-C(6)$); 2.26 ($d\times d\times d$, $J_1=13.5$, $J_2=4$, $J_3=2$, $H_{eq}-C(3)$); 2.30 (*d*, $J=13.5$, H–C(1)); 2.50 ($d\times qi$, $J_1=14$, $J_2=2$, $H_{eq}-C(8)$); 2.70 ($d\times t$, $J_1=14$, $J_2=2.5$, $H_{eq}-C(6)$).

Catalytic hydrogenation (EtOAc, Pt, 20°/730 Torr, uptake 1 H_2) of epimer **I** gave *(4S,4aS,6R,8aR)-6-Isopropyl-4,8a-dimethyl-perhydronaphthalen-2-one* (**8a**). – ^{1}H-NMR[1]): 0.92 (*s*, $H_3C-C(10)$); 0.89–0.93 (2 *d*, $J=7$, 2 $H_3C-C(11)$); 0.97 (*d*, $J=6.5$, $H_3C-C(4)$); 1.0–1.6 (miscellaneous *m*, 8 H); 1.68 (*d*, $J=14$, H–C(1)); 2.02–2.16 (*m*, 2 H–C(3)); 2.36 (after $H_3C-C(4)$ decoupling: $d\times t$, $J_1=12$, $J_2=5$, $H-C(4)$); 2.62 (*d*, $J=14$, H–C(1)).

Similarly hydrogenated, above epimer **II** gave *(4R,4aS,6R,8aR)-6-Isopropyl-4,8a-dimethyl-perhydronaphthalen-2-one* (**8b**). – ^{1}H-NMR[1]): 0.89–0.92 (2 *d*, $J=6.5$, 2 $H_3C-C(11)$); 1.03 (*s*, $H_3C-C(10)$); 1.15 (*d*, $J=7$, $H_3C-C(4)$); 1.2–1.6 (miscellaneous *m*, 6 H); 1.70 (*d*, $J=14$, H–C(1)); 2.08 (*m*, 2 H); 2.59 (*m*, 1 H); 2.66 (*d*, $J=14$, H–C(1)).

Both **8a** and **8b** proved to be spectrally identical (^{1}H-NMR) with the hydrogenation product of **7a** and **7b**, resp. *(Sect. 3.3)*.

3.6. *MS of* **P** *and* **Q**. *(+)-α-Cyperone* (**P**) [13]: 218 (100, M^+, $C_{15}H_{22}O$), 203 (35), 190 (7), 175 (56), 161 (63), 147 (80), 136 (64), 121 (76), 105 (66), 91 (89), 79 (68), 67 (57), 55 (54), 41 (63).

MS of (−)-10-Epi-α-cyperone (**Q**) [14]: 218 (23, M^+, $C_{15}H_{22}O$), 203 (22), 190 (26), 175 (43), 161 (56), 147 (75), 132 (87), 119 (65), 105 (74), 91 (87), 79 (75), 67 (63), 55 (75), 41 (100).

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