114. Preparation of Campholenal Analogues: Chirons for the Lipophilic Moiety of Sandalwood-Like Odorant Alcohols

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Dedicated to the memory of Dr. *A.F. Thomas*

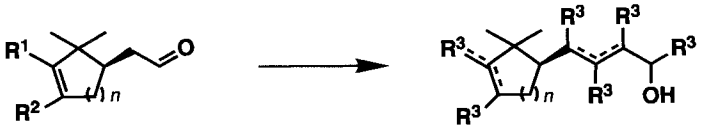
(4.VI.92)

In connection with structure-activity relationship studies, analogues of campholenal ((+)-**4b**), an important building block for sandalwood-like odorants, were prepared. The five-membered-ring analogues **4** were obtained by epoxidation of the corresponding α-pinene derivatives **2**, followed by catalytic $ZnBr_2$ isomerisation (*Scheme 2*). The six-membered-ring skeleton was obtained by ozonolysis of α-campholenyl acetate ((−)-**14b**), followed by intramolecular aldol condensation (*Scheme 5*). ^{13}C-NMR assignments are given.

Introduction. – Information concerning the structure of a receptor is of great interest for the design of biologically active compounds. Whereas several examples of X-ray structure analyses of a particular receptor are known in the case of pharmaceutical applications [1], there are unfortunately no such examples for olfactory receptors. Because of this fact, receptor mapping [2] is dependent on a large data base of analogues, which allow the determination, either empirically or analytically, of the primordial factors of interaction. These include steric hindrance, intramolecular distances [3], cavity or space-filling concepts [4], lipophilicity [5], associated with molecular surfaces [6] and volumes [7], hydrophobicity [8], allied with accessible polar surfaces [9], dipole moment [10], and the partition coefficient between H_2O and octanol [11], binding energy [12], electrostatic potential [13], *etc.*

To test diverse statistical approaches based on connectivity [14a,b], analogy and intelligence in model-building techniques [14c], expert systems [15], or neural networks [16], we selected a series of sandalwood-like odorant alcohols of structure type **A** (*Scheme 1*) derived from campholenal (= 2,2,3-trimethylcyclopent-3-ene-1-acetaldehyde; (+)-

Scheme 1



(+)-**1** R^1 = H, R^2 = Me, n = 1 **A** R^3 = H, alkyl, dialkyl, n = 1,2

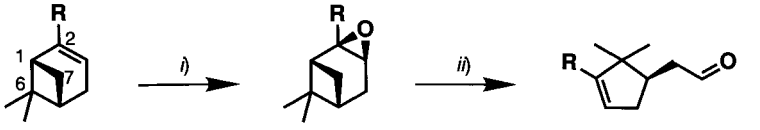
4b), which would comprise a large data base [17] for a well-defined characteristic odour. Indeed, multiple variations of the hydrophilic part of the molecule were already described in the literature [18], but our specific interest was to increase our knowledge concerning

the lipophilic part by structural modification of the campholenic moiety, so as to retain an optimal common fit [19] and to determine the influence of neuralgic substitutions, unsaturation, or configuration.

In the following, we describe the syntheses of series of five- and six-membered-ring acetaldehydes suitable to be transformed to alcohols of type **A**. The preparation and olfactive properties of the latter will be reported in due course.

Results. – a) *Five-Membered-Ring Analogues.* Fencholenal (= 2,2,4-trimethylcyclopent-3-ene-1-acetaldehyde; (+)-**1**) [20] recently received particular attention as an analogue of (+)-**4b**, although its synthesis requires the use of an expensive Ag salt. This prompted us to prepare the analogues **4c–o** of campholenal ((+)-**4b**) [21] by modification of the substrate **3** in the well known modified *Arbuzow* preparation [22], involving the isomerisation of α-pinene epoxide ((−)-**3b**) [23] in the presence of a catalytic amount of $ZnBr_2$ in refluxing toluene (*Scheme 2*). The known rapid rearrangement of epoxide (−)-**3a** [24] to aldehyde (+)-**4a** [25] under the same conditions supported our choice of approach. The substrates **3** were all obtained from their precursors **2** by epoxidation with AcO_2H.

Scheme 2



R = H	(−)-**2a**		(−)-**3a**	(35%)	(+)-**4a**	(75%)
Me	**b**		**b**	(78%)	**b**	(75%)
Et	**c**		**c**	(86%)	**c**	(64%)
Pr	**d**		**d**	(93%)	**d**	(70%)
Bu	**e**	(85%[a]))	**e**	(88%)	**e**	(72%)
$(CH_2)_2OH$	**f**		**f**	(86%)	**f**	(61%; 80%[b]))
$(CH_2)_2OAc$	**g**		**g**	(83%)	**g**	(69%)
$(CH_2)_2OMe$	**h**		**h**	(87%)	**h**	(65%)
$(CH_2)_2OTs$	**i**		**i**	(85%)	**i**	(0%; 87%[c]))
Vinyl	**j**		**j**	(37%)	**j**	(10%; 53%[d]))
$(CH_2)_2COMe$	**k**	(88%[e]; 73%[f]))	**k**	(90%)	**k**	(35%)
$(CH_2)_2CO_2Et$	**l**	(67%[f]))	**l**	(82%)	**l**	(67%)
CH_2OMe	**m**		**m**	(68%)	**m**	(58%)
CH_2OEt	**n**	(74%[g]))	**n**	(79%)	**n**	(53%)
$(CH_2)_3CO_2Me$	**o**		**o**	(93%)	**o**	(64%)

i) AcO_2H, AcOH, $NaHCO_3$, toluene. *ii*) 0.05 mol-equiv. of $ZnBr_2$, toluene, 110°.

[a]) From (−)-**2k**. [b]) From (+)-**4g**. [c]) From (+)-**4f**. [d]) Yield of (−)-**5a** (*Scheme 3*). [e]) From (−)-**8** (*Scheme 3*). [f]) From (+)-**10**. [g]) From (−)-myrtenol.

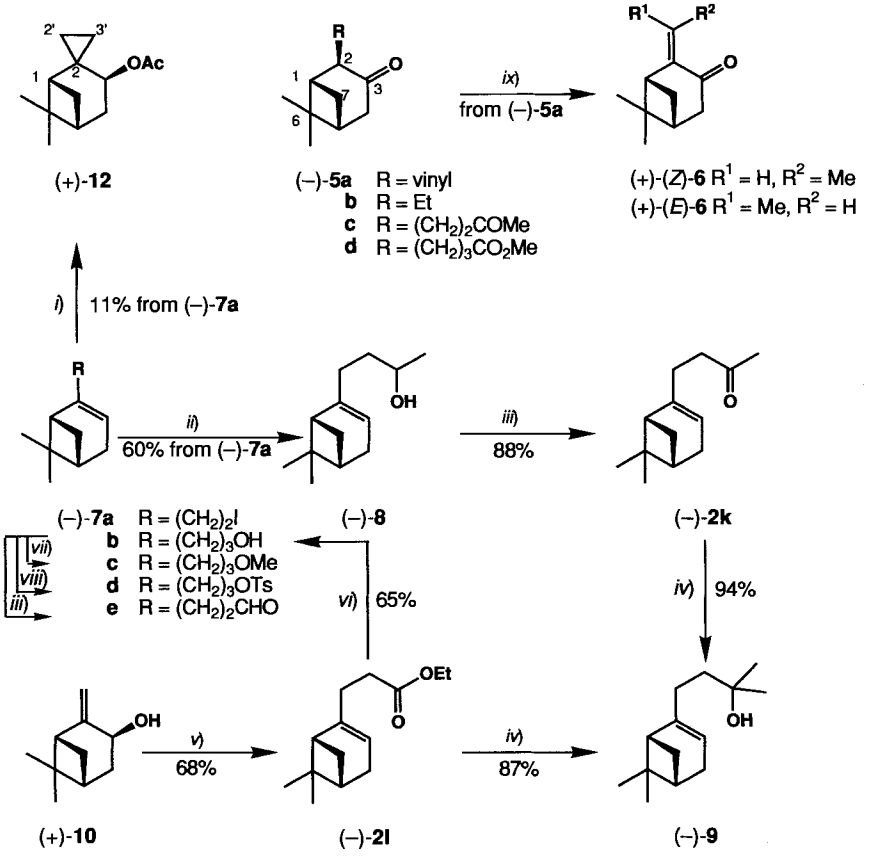
Under the conditions described above, ethylapopinene epoxide ((−)-**3c**) analogously rearranged to aldehyde (+)-**4c** in 64% yield. To have general access to higher alkylated homologues, we added methyl cuprate [26] to tosylate (−)-**2i** [27] and isolated propylapopinene ((−)-**2d**; 85% yield) [28]. The butyl homologue (−)-**2e** [29] was obtained in 85% yield by the *Huang-Minlon* modification of the *Wolff-Kishner* reduction [30] (N_2H_4, KOH, ethylene glycol) of ketone (−)-**2k** [31]. The corresponding epoxides (−)-**3d** (93%)

and (−)-**3e** (88%) were subsequently rearranged to aldehydes (+)-**4d** (70%) and (+)-**4e** (72%), respectively.

The commercially available nopol ((−)-**2f**) and nopyl acetate ((−)-**2g**) [32] afforded epoxides (−)-**3f** (86%) [33] and (−)-**3g** (83%), whose subsequent isomerisation to (+)-**4f** (61%) and (+)-**4g** (69%), respectively, proceeded smoothly despite the possible deactivation of $ZnBr_2$ by chelation with the supplementary heteroatom. An alternative approach to (+)-**4f** consisted in saponification of (+)-**4g** (LiOH, THF/H_2O 5:4; 80%). Epoxide (−)-**3h** was isomerised to methoxy-aldehyde (+)-**4h** in 65% yield. The thermally unstable epoxy sulfonate (−)-**3i** (85% from (−)-**2i**) decomposed violently on heating, and even in solution, it did not withstand the isomerisation conditions; tosylate (+)-**4i** was, therefore, prepared from alcohol (+)-**4f** (TsCl, pyridine, 87%).

Epoxidation of (1*R*)-nopadiene ((−)-**2j**) [34][1]) furnished a complex mixture of mono- and di-epoxides (70:5:2:12:11) from which the major component (−)-**3j**, was obtained in

Scheme 3



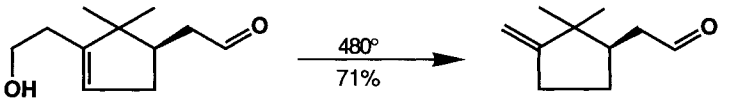
i) AcO_2H, AcOH, $NaHCO_3$, toluene. *ii*) Mg, Et_2O. CH_3CHO. *iii*) Pyridinium chlorochromate, CH_2Cl_2. *iv*) MeMgI, Et_2O. *v*) $HC(OEt)_3$, $C_5H_{11}CO_2H$. *vi*) $LiAlH_4$, Et_2O. *vii*) NaH, THF, MeI. *viii*) TsCl, pyridine. *ix*) NaOMe, MeOH.

37% yield after distillation. Isomerisation of (−)-**3j** gave a 16:64:20 mixture of (+)-**4j**, (−)-**5a**, and (+)-(*Z*)-**6** (see *Scheme 3*) from which the unstable dienal (+)-**4j** (10%) [35] and ketone (−)-**5a** (53%) were isolated. The presence of (−)-**5a** is explained by the fact that the stabilised allylic carbocationic intermediate favours isomerisation to a ketone as opposed to skeletal rearrangement to an aldehyde. Base treatment of (−)-**5a** and (+)-(*Z*)-**6** (5% MeONa, MeOH, 90% yield) afforded exclusively the known enone (+)-(*E*)-**6** (*Scheme 3*) [36].

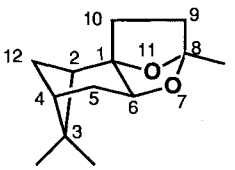
Methyl ketone (−)-**2k**[2]) was obtained by a *Carroll* reaction on (+)-*trans*-pinocarveol ((+)-**10**) [41], and epoxidation gave (−)-**3k**[3]) (90%) which was isomerised to a 76:24 mixture of aldehyde (+)-**4k** (35%) and ketone (−)-**5c** (18%), purified by chromatography. In contrast, epoxy ester (−)-**3l** [42] cleanly rearranged to aldehyde (+)-**4l** (67%).

Epoxidation of methyl myrtenyl ether ((−)-**2m**) [43] gave rise to (−)-**3m** (68%) followed by clean isomerisation to the volatile aldehyde (+)-**4m** (58%). Similarly, epoxide

Scheme 4



(+)-**4f** (+)-**13**



(−)-**11**

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[1]) Pure **2j** (99.9% by GC) is levorotatory neat ($\alpha_D^{20} = -1.4$) and dextrorotatory in solution ($[\alpha]_D^{20} = +5.8$ ($c = 8.25$, hexane); [34]: $[\alpha]_D^{24} = +3.8$ ($c = 8.4$, hexane) and $[\alpha]_D^{20} = +1.2$ ($c = 1.8$, $CHCl_3$); [27]: $[\alpha]_D^{20} = +1.3$ ($c = 1.5$, $CHCl_3$)).

[2]) Also prepared from (−)-myrtenyl bromide, **2k** is described as dextrorotatory ($[\alpha]_D^{17} = +26.1$ ($c = 2.08$, MeOH)) [31a]; this is in disagreement with our observations ($[\alpha]_D^{20} = -36.9$ ($c = 2.3$, MeOH)). For this reason, we correlated (−)-**2k** with (−)-nopol ((−)-**2f**) as follows (*Scheme 3*): tosylate (−)-**2i** [27] was converted to iodide (−)-**7a** in 93% yield (EtMgI, Et_2O; these new reaction conditions for the transformation of a primary tosylate to its corresponding halide were recently discovered in our laboratory and will be reported in due course), and the corresponding *Grignard* reagent was added to acetaldehyde to give the secondary alcohol (−)-**8** in 60% yield. Oxidation (pyridinium chlorochromate, CH_2Cl_2; 88% yield) afforded (−)-**2k** ($[\alpha]_D^{20} = -38.1$ ($c = 2.1$, MeOH)) which was treated with a methyl *Grignard* reagent to give the tertiary alcohol (−)-**9** (94% yield; $\alpha_D^{20} = -25.1$) with the same absolute configuration as that obtained by a double addition of methyl *Grignard* reagent to (−)-**2l** [37] ($[\alpha]_D^{20} = -24.4$; 87% yield). The fact that oxidation (CrO_3; 78% yield) of (+)-*trans*-pinocarveol ((+)-**10**) ($\alpha_D^{20} = +53$) gave (+)-pinocarvone ($\alpha_D^{20} = +52.7$ (neat)) [38] and that (−)-**2d** ($\alpha_D^{20} = -26.3$ (neat)) was also obtained from the hydride reduction ($LiAlH_4$, 76%) of tosylate (−)-**7d**, prepared from alcohol (−)-**7b** [39], confirms the absolute configuration of all compounds described in our work [40]. After completion of this correlation, we were informed by Dr. *A. Kazubski* of a printing error in [31a].

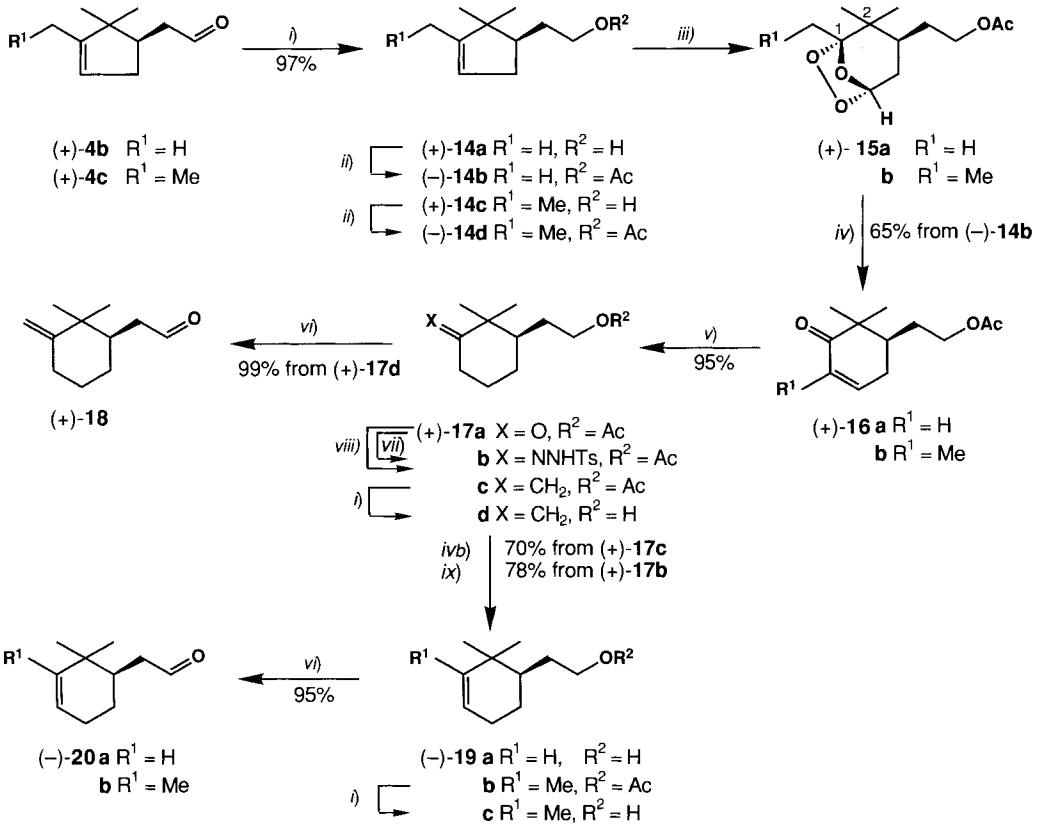
[3]) Epoxide (−)-**3k** is sensitive to acidic conditions and readily gave acetal (−)-**11** (see *Scheme 4*).

(−)-**3n** (79% from (−)-**2n**) afforded homologue (+)-**4n** in 53% yield. Aldehyde (+)-**4o**, finally, was obtained from (−)-**2o** [44] (59% yield) and represents, with (+)-**4f** (and (+)-**4c**), a potential homologue of (+)-**4b**, after appropriate transformations. Epoxidation of iodide (−)-**7a** resulted in the formation of a mixture of (−)-**2g** (22%), (−)-**3g** (20%), and (+)-**12** (44%, *Scheme 3*) [45].

Finally, aldehyde (+)-**13** [46], with an exocyclic C=C bond, was obtained selectively in 71% yield from (+)-**4f** by a thermal *retro-Prins* reaction (*Scheme 4*).

b) *The Six-Membered-Ring Analogues.* The absolute configuration is an important factor for a comparison of organoleptically active compounds [47], and to retain the same absolute configuration, we decided to use campholenal ((+)-**4b**) as a chiral starting material. Oxidative degradation followed by intramolecular aldol condensation, leading to chiral cyclohexanones, was already applied to syntheses of (−)-khusimone [48a, b] and (+)-norpatchoulenol [48c]. Following the same methodology, alcohol (+)-**14a** [49], obtained from (+)-**4b** in 97% yield, was acetylated to acetate (−)-**14b** [50] (*Scheme 5*);

Scheme 5



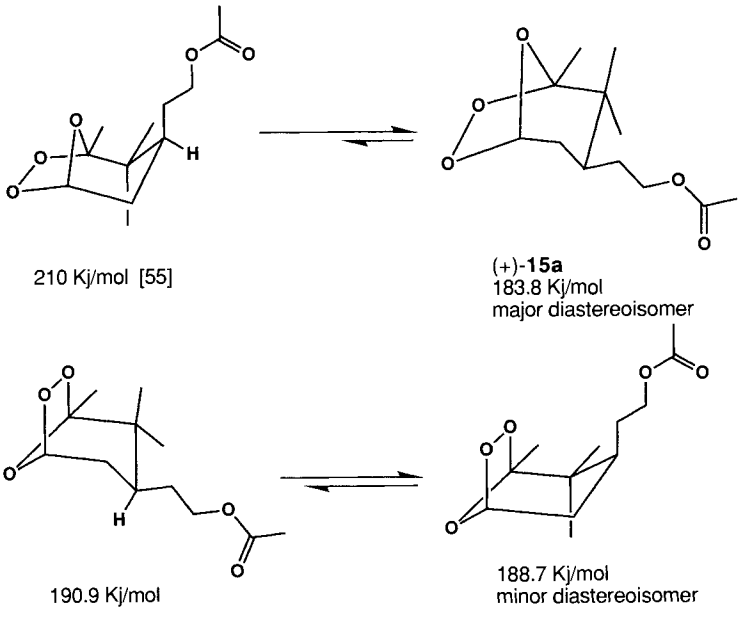
i) $LiAlH_4$, Et_2O. *ii*) Ac_2O, H_3PO_4. *iii*) O_3, CH_2Cl_2, MeOH, −70°. *iv*) *a*) Me_2S, 20°, 24 h; *b*) TsOH, cyclohexane, 100°. *v*) H_2, *Raney*-Ni, EtOH. *vi*) Pyridinium chlorochromate, CH_2Cl_2. *vii*) NH_2NHTs, MeOH, cat. H_2SO_4. *viii*) $[PPh_3(Me)]I$, *t*-BuOK, toluene. *ix*) MeLi, Et_2O, −5°.

subsequent ozonolysis gave a mixture of diastereoisomeric ozonides from which the major component (+)-**15a** was isolated and fully characterised. Reductive workup (Me_2S) of the crude mixture of ozonides and cyclisation (TsOH, refluxing cyclohexane) gave cyclohexenone (+)-**16a** (65% from (−)-**14b**). The homologue (+)-**16b**, a potential chiron for the synthesis of either (*R*)-verticillene [51] or (2*R*,6*R*,2′*R*,6′*R*)-decaprenoxanthin [52], was similarly obtained from aldehyde (+)-**4c** *via* (+)-**14c**, (−)-**14d**, and (+)-**15b**. Catalytic hydrogenation of (+)-**16a** (H_2, *Raney*-Ni; 95%) gave cyclohexanone (+)-**17a** which was submitted to a *Wittig* reaction ([PPh_3(Me)]I, *t*-BuOK, toluene; 72%) to afford the desired acetate (+)-**17c**. Deprotection ($LiAlH_4$, Et_2O; → **17d** 96%) and oxidation (pyridinium chlorochromate, CH_2Cl_2; 99%) gave the target aldehyde (+)-**18**, a homologue of (+)-**13** (see *Scheme 4*).

Alcohol (−)-**19a**, obtained by a *Shapiro* reaction [53] from cyclohexanone (+)-**17a** *via* hydrazone **17b** in 68% overall yield, was similarly oxidised to aldehyde (−)-**20a** (95%), a homologue of (+)-**4a** (see *Scheme 2*). The exocyclic C=C bond of (+)-**17c** was isomerised into the endocyclic position (TsOH, refluxing toluene) to afford acetate (−)-**19b** (70%). The same sequence of deprotection (→ **19c**) and oxidation steps furnished the six-membered-ring campholenal analogue (−)-**20b** (87% overall yield from (−)-**19b**).

Concerning the ozonides, purified by chromatography [54], it was clear from the ^{13}C-NMR analysis that the major diastereoisomer has an equatorial side chain (δ(C(3)) = 38.1 ppm) attributed to the more stable conformer (+)-**15a**. The axial side chain (δ(3) = 33.9 ppm) was in accord with the slightly more stable conformer of the minor diastereoisomer (*Scheme 6*).

Scheme 6



We are indebted to Dr. *K.-H. Schulte-Elte* for constant stimulating discussions and Dr. *B. Winter* for MM2 calculations of the diastereoisomers and conformers of (+)-**15a** as well as Mrs. *B. Baer*, Miss *C. Cantatore*, and Mr. *M. Wuest* for their experimental skill.

Experimental Part

General. All reactions were performed under N_2. GLC: *Hewlett Packard 5890* instrument equipped with a flame ionization detector coupled to a *Hewlett Packard 3396 A* integrator; capillary columns *Chrompack. DB-Wax* (15 m, 0.25 mm), and *DB-1* (15 m, 0.25 mm). Prep. GLC: *Varian 700*, packed columns *Carbowax* (6 m, 0.6 cm). TLC: silica gel *60* (*Merck F 254*, layer thickness 0.25 mm). Prep. CC: silica gel *60* (*Merck*, 0.063–0.2 mm, 70–230 mesh, ASTM). Bulb-to-bulb distillation: *Büchi GKR-50* oven; b.p. correspond to the air temp. Optical rotations: *Perkin Elmer-241* polarimeter; with pure material, when solvent and concentration not specified. IR spectra (liquid film): *Perkin-Elmer-297* spectrometer; in cm^{-1}. NMR: *Bruker WH-360*, *Bruker AMX-360*; ^1H at 360 and ^{13}C at 90 MHz (*Tables 1–6*); in $CDCl_3$; chemical shifts (δ) in ppm rel. to TMS; 2D experiments such as COSY and C/H correlations were performed when necessary. MS: *Varian MAT-112* spectrometer (*ca.* 70 eV); intensities in % rel. to the base peak (100%).

Starting Materials. (−)-**2a** [56], $\alpha_D^{20} = -47.2$, 98% e.e.; (−)-**2b** (*Aldrich*), $\alpha_D^{20} = -50.7$, 98% e.e.; (−)-**2c** [57], $[\alpha]_D^{20} = -48.1$ ($c = 1.9$, $CHCl_3$), 90% e.e.; (−)-**2d** [28], $\alpha_D^{20} = -30.1$, 92% e.e.; (−)-**2f** (*Fluka AG*), $\alpha_D^{20} = -35.6$, 90% e.e.; (−)-**2g** (*Rhône Poulenc*), $\alpha_D^{20} = -31.9$, 90% e.e.; (−)-**2h** [58], $\alpha_D^{20} = -29.8$, 91% e.e.; (−)-**2i** [27], $[\alpha]_D^{20} = -28.5$ ($c = 2.3$, MeOH), 96% e.e.; (−)-**2m** [43], $\alpha_D^{20} = -30.0$, 94% e.e.; (−)-**2o** [44], $\alpha_D^{20} = -23.1$, 92% e.e.; (−)-**7e** [59], $\alpha_D^{20} = -31.1$, 85% e.e.

General Procedure A for the Preparation of Epoxides. To a suspension of Na_2CO_3 (238 g, 2.24 mol), EDTA tetrasodium salt (6.5 g, 17 mmol), and the corresponding olefin (1.4 mol) in toluene (700 ml) was added dropwise at 20° (exothermic) a 40% soln. of AcOOH (400 g, 2.1 mol). The mixture was stirred at r.t., until no more starting material was detected by GLC (*ca.* 2–15 h), then H_2O (180 ml) was added dropwise. The mixture was diluted with toluene (300 ml), washed successively with H_2O, sat. aq. $NaHCO_3$ soln., and brine, dried (Na_2SO_4), and evaporated. The crude oil was distilled over a 15-cm *Vigreux* column to afford the epoxide as a colourless oil.

General Procedure B for the Isomerisation of Epoxides to Aldehydes Using $ZnBr_2$. To a suspension of anh. $ZnBr_2$ (1.1 g, 5 mmol) in refluxing toluene (100 ml) was added dropwise a soln. of the corresponding epoxide (1 mol) in toluene (250 ml). The mixture was stirred at reflux temp., until no more starting material was detected by GLC (*ca.* 2–18 h). After cooling at r.t., a soln. of AcOH (2 ml) in H_2O (130 ml) was added. The mixture was diluted with toluene (150 ml), washed successively with H_2O, sat. aq. $NaHCO_3$ soln., and brine, dried (Na_2SO_4), and evaporated.

(−)-(1R)-2-Butyl-6,6-dimethylbicyclo[3.1.1]hept-2-ene ((−)-**2e**). A mixture of diethylene glycol (140 ml), KOH (20 g, 360 mmol), (−)-**2k** (20 g, 0.104 mol) and hydrazine hydrate (80%; 15 ml, 0.17 mol) was heated at reflux (130°) for 1.5 h under continuous removal of the H_2O formed (*Dean-Stark* apparatus). The temp. was then raised to 200° during 2.5 h, and the mixture was cooled to 0°. H_2O (145 ml) and 6N HCl (85 ml) were then cautiously added. The mixture was extracted with cyclohexane and the combined extract successively washed with H_2O and brine, dried (Na_2SO_4), and evaporated. The crude oil (19.1 g) was purified by CC (SiO_2, 345 g, cyclohexane): (−)-**2e** (15.6 g, 85%). Colourless oil after bulb-to-bulb distillation. B.p. 81°/10 Torr. $\alpha_D^{20} = -23.7$. IR: 2950, 1480, 1400, 1380. ^1H-NMR: 0.84 (*s*, 3 H); 0.90 (*t*, $J = 7$, 3 H); 1.16 (*d*, $J = 7$, 1 H); 1.26 (*s*, 3 H); 1.3 (*m*, 4 H); 1.93 (*m*, 2 H); 2.0 (*t*, $J = 5$, 1 H); 2.07 (*m*, 1 H); 2.2 (*m*, 2 H); 2.35 (*dt*, $J = 5.8$, 1 H); 5.16 (br. *s*, 1 H). ^{13}C-NMR: *Table 1*. MS: 178 (7, $M^{+\cdot}$), 135 (19), 121 (18), 105 (15), 93 (48), 79 (71), 57 (100), 41 (39).

(−)-(1′R)-4-(6′,6′-Dimethylbicyclo[3.1.1]hept-2′-en-2′-yl)butan-2-one ((−)-**2k**). To a suspension of pyridinium chlorochromate (3.23 g, 15 mmol) in CH_2Cl_2 (5 ml) was added dropwise a soln. of (−)-**8** (1.94 g, 10 mmol) in CH_2Cl_2 (5 ml). The mixture was stirred overnight at r.t., diluted with Et_2O (50 ml), filtered over *Celite*, washed successively with 15% aq. HCl soln., H_2O, and brine, dried (Na_2SO_4), and evaporated. The crude oil (2.1 g) was chromatographed (SiO_2, 100 g, cyclohexane/AcOEt 9:1): (−)-**2k** (1.69 g, 88%). Colourless oil after bulb-to-bulb distillation. B.p. 86°/1 Torr. $[\alpha]_D^{20} = -38.1$ ($c = 2.1$, MeOH). IR: 2990, 2920, 1720, 1440, 1360, 1160. ^1H-NMR: 0.81 (*s*, 3 H); 1.13 (*d*, $J = 7$, 1 H); 1.27 (*s*, 3 H); 1.98 (*t*, $J = 5$, 1 H); 2.08 (*m*, 1 H); 2.15 (*s*, 3 H); 2.22 (*m*, 4 H); 2.35 (*dt*, $J = 5, 8$, 1 H); 2.48 (*t*, $J = 7$, 2 H); 5.2 (br. *s*, 1 H). ^{13}C-NMR: *Table 1*. MS: 192 (1, $M^{+\cdot}$), 177 (2), 159 (3), 149 (16), 134 (20), 119 (42), 105 (13), 91 (100), 79 (15), 43 (43).

(−)-Ethyl (1R)-6,6-Dimethylbicyclo[3.1.1]hept-2-ene-2-propanoate ((−)-**2l**). A mixture of (+)-*trans*-pinocarveol (10 g, 66 mmol; $\alpha_D^{20} = +53$), triethyl orthoacetate (16.2 g, 0.1 mol), and hexanoic acid (1 g, 10 mmol) was heated with continuous distillation of EtOH. The mixture was then diluted with Et_2O (150 ml) and washed successively with sat. aq. $NaHCO_3$ soln. and H_2O, dried (Na_2SO_4), and evaporated. The crude oil (15.7 g) was distilled over a 15-cm *Vigreux* column: (−)-**2l** (9.96 g, 68%). Colourless oil. B.p. 91°/0.25 Torr. $\alpha_D^{20} = -28$. IR: 2960, 2900, 1725, 1460, 1440, 1360. ^1H-NMR: 0.81 (*s*, 3 H); 1.15 (*d*, $J = 7$, 1 H); 1.26 (*t*, $J = 7$, 3 H); 1.28 (*s*, 3 H); 2.0 (*t*, $J = 5$, 1 H); 2.08 (*m*, 1 H); 2.21 (*m*, 2 H); 2.28 (*m*, 2 H); 2.35 (*m*, 3 H); 4.13 (*q*, $J = 7$, 2 H); 5.24 (br. *s*, 1 H). ^{13}C-NMR: *Table 1*. MS: 222 (4, $M^{+\cdot}$), 207 (3), 179 (12), 161 (10), 148 (8), 133 (87), 119 (57), 105 (100), 91 (85), 79 (27), 41 (28).

Table 1. *^{13}C-NMR Data of Compounds (−)-**2a–o**, (−)-**7a–e**, and (−)-**9***

	R	C(1)	C(2)	C(3)	C(4)	C(5)	C(6)	Me_{exo}–C(6)	Me_{endo}–C(6)	C(7)	R								
(−)-**2a**[a])	H	42.1	136.6	124.1	32.6	41.4	38.0	26.5	21.3	32.1									
(−)-**2b**[a])	Me	47.3	144.5	116.2	31.3	41.0	38.1	26.4	20.8	31.5	23.0								
(−)-**2c**	Et	46.0	150.1	114.5	31.3	41.2	38.0	26.4	21.2	31.7	29.7	11.8							
(−)-**2d**	Pr	46.0	148.6	115.8	31.4	41.1	38.0	26.4	21.2	31.7	39.3	20.4	14.0						
(−)-**2e**[a])	Bu	46.0	148.8	115.5	31.3	41.1	38.0	26.4	21.2	31.7	36.7	29.5	22.6	14.0					
(−)-**2f**	$(CH_2)_2OH$	45.8	144.9	119.0	31.4	40.9	38.0	26.3	21.2	31.8	40.3	60.2							
(−)-**2g**	$(CH_2)_2OAc$	45.8	144.3	118.8	31.4	40.9	38.0	26.3	21.1	31.7	36.0	62.7		170.8	20.8				
(−)-**2h**[a])	$(CH_2)_2OMe$	46.0	145.2	117.8	31.4	41.0	38.1	26.4	21.2	31.7	37.1	71.2		58.4					
(−)-**2i**	$(CH_2)_2OTs$	45.7	142.8	119.7	31.3	40.7	38.0	26.2	21.1	31.5	36.1	68.6			144.6	127.9	129.8	133.5	21.6
(−)-**2j**	CH_2=CH	41.2	146.9	124.2	31.3	40.5	37.7	26.4	20.7	31.9	137.8	109.6							
(−)-**2k**[a])	$(CH_2)_2COMe$	46.0	146.9	116.4	31.2	40.9	38.0	26.3	21.1	31.6	30.9	41.4	208.3	29.7					
(−)-**2l**[a])	$(CH_2)_2COOEt$	45.9	146.7	116.7	31.3	40.9	38.0	26.3	21.1	31.6	32.0	32.4	173.4		60.2	14.3			
(−)-**2m**	CH_2OMe	43.5	145.5	119.9	31.3	41.1	38.0	26.3	21.1	31.6	75.6		57.7						
(−)-**2n**	CH_2OEt	43.5	145.8	119.2	31.3	41.1	38.0	26.3	21.0	31.6	73.5		65.2	15.2					
(−)-**2o**[a])	$(CH_2)_3COOMe$	45.8	147.4	116.7	31.3	41.0	38.0	26.4	21.2	31.7	36.3	22.6	33.7	174.0		51.3			
(−)-**7a**	$(CH_2)_2I$	45.5	146.8	118.7	31.3	40.8	38.1	26.3	21.4	31.8	41.5	3.3							
(−)-**7b**	$(CH_2)_3OH$	45.9	147.9	116.2	31.3	41.0	38.0	26.4	21.2	31.7	33.1	30.3	62.8						
(−)-**7c**	$(CH_2)_3OMe$	46.0	147.9	116.1	31.3	41.0	38.0	26.4	21.2	31.7	33.3	27.4	72.7		58.5				
(−)-**7d**	$(CH_2)_3OTs$	45.7	146.5	117.2	31.2	40.9	37.9	26.3	21.1	31.6	32.4	26.5	70.3			144.6	128.0	129.8	133.5	21.6
(−)-**7e**	$(CH_2)_2CHO$	46.0	146.4	117.1	31.3	40.9	38.0	26.3	21.1	31.6	29.3	41.4	202.5						
(−)-**9**	$(CH_2)_2C(CH_3)_2OH$	46.1	148.4	115.8	31.3	41.0	38.0	26.4	21.2	31.8	31.7	41.3	70.8	29.2	29.3				

[a]) 2D Experiments: COSY and C,H correlations.

Table 2. *^{13}C-NMR Data of (−)*-**3a–o**

	R	C(1)	C(2)	C(3)	C(4)	C(5)	C(6)	Me_{exo}–C(6)	Me_{endo}–C(6)	C(7)	R							
(−)-**3a**[a])	H	39.9	54.5	49.7	27.8	40.1	40.7	26.7	19.7	24.4								
(−)-**3b**[a])	Me	45.2	60.2	56.9	27.7	39.8	40.5	26.7	20.2	25.9	22.4							
(−)-**3c**	Et	43.5	63.5	55.3	27.7[b])	40.3	40.7	26.8	20.2	25.8	27.8[a])	7.6						
(−)-**3d**	Pr	43.6	63.0	55.5	27.8	40.2	40.7	26.9	20.3	25.8	37.4	16.9	14.4					
(−)-**3e**	Bu	43.6	63.1	55.6	27.8	40.2	40.7	26.8	20.3	25.8	34.8	25.8	23.0	14.0				
(−)-**3f**	$(CH_2)_2OH$	44.4	63.0	54.9	27.5	40.0	40.6	26.7	20.2	25.6	36.5	58.6						
(−)-**3g**	$(CH_2)_2OAc$	43.9	60.9	55.4	27.6	40.0	40.7	26.8	20.0	25.7	34.0	60.2		170.8	20.9			
(−)-**3h**	$(CH_2)_2OMe$	44.0	61.2	55.7	27.7	40.1	40.7	26.8	20.1	25.8	34.9	68.3		58.4				
(−)-**3i**	$(CH_2)_2OTs$	43.8	60.4	55.5	27.5	39.8	40.6	26.6	20.0	25.7	34.2	66.4		144.8	127.9	129.9	133.2	21.6
(−)-**3j**	CH_2=CH	41.6	61.6	58.1	27.6	40.1	40.4	26.6	20.3	25.7	139.2	116.6						
(−)-**3k**	$(CH_2)_2COMe$	43.8	62.2	55.6	27.6	40.1	40.7	26.7	20.2	25.8	28.7	37.7	208.0	29.8				
(−)-**3l**[a])	$(CH_2)_2COOEt$	43.8	62.1	55.3	27.6	40.1	40.7	26.8	20.2	25.8	30.0	28.6	173.4		60.4	14.2		
(−)-**3m**	CH_2OMe	40.5	62.3	52.8	27.3	40.2	40.7	26.7	20.2	25.5	74.2		59.3					
(−)-**3n**[a])	CH_2OEt	40.6	62.4	52.9	27.4	40.2	40.7	26.7	20.3	25.5	72.3		66.9	15.1				
(−)-**3o**[a])	$(CH_2)_3COOMe$	43.4	62.6	55.3	27.7	40.2	40.7	26.8	20.2	25.7	34.3	19.2	33.9	173.7		51.3		

[a]) 2D Experiments: COSY and C,H correlations.
[b]) Interchangeable.

Table 3. *^{13}C-NMR Data of (+)-**4a–o** and (+)-**13**[a])*

	R	C(1)	C(2)	C(3)	C(4)	C(5)	Me_{cis}–C(5)[b])	Me_{trans}–C(5)[b])	CH_2CHO	CH_2CHO	R							
(+)-**4a**	H	142.1	126.9	37.9	43.1	46.1	22.2	27.8	44.9	202.6								
(+)-**4b**	Me	148.0	121.6	35.6	44.3	47.0	20.1	25.7	45.2	202.7	12.6							
(+)-**4c**	Et	154.1	119.2	35.6	44.6	47.3	20.5	25.8	45.0	202.9	19.7	12.1						
(+)-**4d**[c])	Pr	152.4	119.9	35.7	44.5	47.3	20.5	25.8	45.0	202.9	29.1	21.1	14.2					
(+)-**4e**	Bu	152.6	119.8	35.7	44.5	47.4	20.5	25.8	45.0	202.9	26.5	30.1	22.8	14.0				
(+)-**4f**	$(CH_2)_2OH$	148.6	122.0	35.8	44.1	47.5	20.5	25.8	44.9	202.7	30.2	61.2						
(+)-**4g**	$(CH_2)_2OAc$	147.9	122.1	35.9	44.0	47.4	20.4	25.7	44.9	202.4	26.1	63.3		170.9	20.9			
(+)-**4h**	$(CH_2)_2OMe$	148.9	121.2	35.9	44.1	47.5	20.5	25.8	44.9	202.7	27.0	71.6		58.6				
(+)-**4i**	$(CH_2)_2OTs$	146.5	122.8	35.9	43.9	47.4	20.4	25.6	44.8	202.3	26.5	69.0			144.8	128.0	129.8	133.5	21.6
(+)-**4k**	$(CH_2)_2COMe$	151.1	120.3	35.6	44.4	47.4	20.4	25.7	44.9	202.6	20.8	41.8	208.2	29.8				
(+)-**4l**	$(CH_2)_2COOEt$	150.9	120.4	35.7	44.4	47.4	20.4	25.7	44.9	202.6	22.1	32.6	173.4		60.3	14.2		
(+)-**4m**	CH_2OMe	148.4	125.4	35.7	44.8	46.5	20.9	25.8	44.7	202.4	69.4		58.0					
(+)-**4n**[c])	CH_2OEt	148.7	125.0	35.7	44.9	46.5	20.9	25.8	44.7	202.5	67.3		65.7	15.2				
(+)-**4o**	$(CH_2)_3COOMe$	151.3	120.7	35.7	44.4	47.4	20.5	25.8	44.9	202.6	26.2	23.2	33.9	174		51.4		
(+)-**13**[c])	$(CH_2=)$	160.7	30.6	28.4	44.4	43.9	23.6	26.6	44.9	202.4	103.8							

[a]) For convenience, the five-membered ring is always numbered in a counter-clockwise direction, with C(1) being substituted by R; for systematic names, see *Exper. Part.*

[b]) *cis/trans* relative to the CH_2CHO side chain.

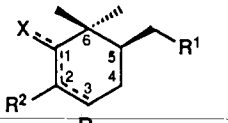
[c]) 2D Experiments: COSY and C,H correlations.

Table 4. *^{13}C-NMR Data of Compounds* **14**[a])

	R^1	R^2	C(1)	C(2)	C(3)	C(4)	C(5)	Me_{cis}–C(5)[b])	Me_{trans}–C(5)[b])	CH_2CH_2O	CH_2OR_2	R^2		R^1	
(+)-**14a**	H	H	148.6	121.7	35.6	46.9	46.9	19.8	25.8	33.4	62.5			12.6	
(−)-**14b**	H	Ac	148.5	121.6	35.4	47.1	46.9	19.7	25.7	29.1	64.3	171.1	21.0	12.5	
(+)-**14c**	Me	H	154.8	119.2	35.6	47.2	n.v.	20.2	25.9	33.2	62.6			19.7	12.2
(−)-**14d**	Me	Ac	154.7	119.2	35.5	47.4	47.2	20.2	25.8	29.0	64.3	171.1	21.0	19.7	12.2

[a]) See *Footnote a* in *Table 3.*

[b]) *cis/trans* relative to the $CH_2CH_2OR^2$ side chain.



B

Table 5. *^{13}C-NMR Data of Compounds* **16**–**20**[a])

	R^1	R^2	X	C(1)	C(2)	C(3)	C(4)	C(5)	C(6)	Me_{cis}–C(6)[b])	Me_{trans}–C(6)[b])	R^1CH_2	R^1			R^2	X
(+)-**16a**[c])	CH_2OAc	H	O=	203.8	128.2	146.9	28.7	40.5	45.1	18.9	22.3	28.6	62.7	170.8	20.8		
(+)-**16b**[c])	CH_2OAc	Me	O=	204.1	133.8	141.6	28.5	40.8	44.9	18.9	22.6	28.7	62.8	171.0	20.9	16.4	
(+)-**17a**[c])	CH_2OAc	H	O=	215.3	37.8	25.0	26.4	44.5	48.7	19.9	22.7	29.1	63.2	171.0	20.9		
(+)-**17c**[c])	CH_2OAc	H	CH_2=	156.7	33.1	26.6[d])	27.5[d])	43.9	39.4	22.0	26.2	29.1	63.9	171.1	21.0		105.9
(+)-**17d**[c])	CH_2OH	H	CH_2=	157.0	33.2	26.8[d])	27.7[d])	43.7	39.4	22.0	26.2	33.4	62.2				105.7
(+)-**18**[c])	CHO	H	CH_2=	155.6	32.9	28.6	26.2	41.3	39.1	22.5	26.4	45.6	202.7				106.6
(−)-**19a**[c])	CH_2OH	H	H	138.9	124.0	25.4	24.2	40.3	34.6	23.2	28.9	33.4	61.9				
(−)-**19b**	CH_2OAc	H	Me	140.9	121.6	24.9	23.7	41.5	37.1	21.4	26.0	29.1	64.0	171.2	21.0		19.3
(−)-**19c**[c])	CH_2OH	H	Me	141.1	121.6	25.1	23.9	41.2	37.1	21.4	26.0	33.3	62.2				19.3
(−)-**20a**[c])	CHO	H	H	124.2	138.0	24.9	25.0	38.3	34.2	23.6	29.0	45.4	202.9				
(−)-**20b**[c])	CHO	H	Me	140.3	121.7	24.4	24.7	39.2	36.8	22.0	26.4	45.4	203.2				19.3

[a]) Numbering according to **B**; systematic names in the *Exper. Part.*

[b]) *cis*/*trans* relative to the R^1CH_2 side chain.

[c]) 2D Experiments: COSY and C,H correlations.

[d]) Interchangeable.

Table 6. *^{13}C-NMR Data of (−)-***5a**–**d** *and* **6**

	$R(R^1,R^2)$	C(1)	C(2)	C(3)	C(4)	C(5)	C(6)	Me_{exo}–C(6)	Me_{endo}–C(6)	C(7)	$R(R^1,R^2)$				
(−)-**5a**[a])	CH_2=CH	42.2	56.1	211.8	44.6	38.1	39.2	26.4	20.0	29.8	135.0	116.5			
(−)-**5b**	Et	41.1	53.7	214.8	44.6	38.2	39.2	26.6	19.9	29.2	22.5	12.1			
(−)-**5c**[a])	$(CH_2)_2COMe$	42.6	50.8	214.3	44.7	38.2	39.4	26.5	19.9	29.3	24.1	41.6	208.4	29.9	
(−)-**5d**[a])	$(CH_2)_3CO_2Me$	41.6	51.7	214.2	44.5	38.1	39.3	26.5	19.9	29.2	29.0	22.9	34.0	173.8	51.5
(+)-(*E*)-**6**	Me,H(*E*)	41.9	142.5	199.7	42.6	38.5	40.7	26.3	21.4	32.3	129.9	12.8			
(+)-(*Z*)-**6**	H,Me(*Z*)	50.6	141.0	201.9	43.9	38.4	40.8	26.1	21.5	32.6	135.5	15.4			

[a]) 2D Experiments: COSY and C,H correlations.

(−)-(1R)-2-(Ethoxymethyl)-6,6-dimethylbicyclo[3.1.1]hept-2-ene ((−)-**2n**). To a suspension of NaH (14.8 g 80% in mineral oil; 0.49 mol) in THF (800 ml) was added dropwise a soln. of (−)-myrtenol (= (−)-6.6-dimethylbicyclo[3.1.1]hept-2-ene-2-methanol; 50 g, 0.329 mol; $\alpha_D^{20} = -47.5$) in THF (200 ml). When the evolution of H_2 had ceased, EtBr (53.7 g, 0.49 mol) was added dropwise and the mixture stirred overnight at r.t., before being quenched with H_2O (50 ml). The mixture was washed successively with 10% aq. HCl soln., H_2O and brine, dried (Na_2SO_4), and evaporated. The crude oil (61 g) was distilled over a 15-cm column packed with helices to give (−)-**2n** (43.8 g, 0.24 mol; 74%). Colourless oil. B.p. 30°/0.018 Torr. $\alpha_D^{20} = -28.4$. IR: 2950, 2900, 1080. ^{1}H-NMR: 0.84 (*s*, 3 H); 1.19 (*d*, *J* = 7, 1 H); 1.20 (*t*, *J* = 7, 3 H); 1.29 (*s*, 3 H); 2.10 (*m*, 1 H); 2.17 (*t*, *J* = 5, 1 H); 2.27 (*m*, 2 H); 2.40 (*dt*, *J* = 8, 5, 1 H); 3.44 *q*, *J* = 7, 2 H); 3.83 (*s*, 2 H); 5.47 (br. *s*, 1 H). ^{13}C-NMR: *Table 1*. MS: 180 (1, M^+), 136 (20), 119 (43), 91 (100), 79 (28), 59 (77), 41 (23).

(−)-(1R,2R,3S)-2,3-Epoxy-6,6-dimethylbicyclo[3.1.1]heptane ((−)-**3a**). Obtained in 35% yield from (−)-**2a** according to *Procedure A*. M.p. 37–39° (petroleum ether). $[\alpha]_D^{20} = -91.8$ (*c* = 5.8, $CHCl_3$). IR: 2890, 1400, 1250, 980, 860. ^{1}H-NMR: 0.98 (*s*, 3 H); 1.21 (*d*, *J* = 7, 1 H); 1.99 (*s*, 3 H); 1.70 (*m*, 2 H); 1.97 (*m*, 2 H); 2.20 (*m*, 1 H); 3.23 (*t*, *J* = 4, 1 H). ^{13}C-NMR: *Table 2*. MS: 138 (1, M^+), 123 (19), 105 (18), 95 (47), 79 (28), 67 (100), 55 (28), 41 (65), 39 (44).

(−)-α-Pinene Epoxide ((−)-**3b**). Obtained in 78% yield from (−)-**2b** according to *Procedure A*. B.p. 102°/50 Torr. $[\alpha]_D^{20} = -103.9$ (*c* = 4.1, $CHCl_3$). IR: 2930, 1440, 1385, 1095, 850. ^{1}H-NMR: 0.95 (*s*, 3 H); 1.3 (*s*, 3 H); 1.35 (*s*, 3 H); 1.61 (*d*, *J* = 8, 1 H); 1.73 (*m*, 1 H); 1.97 (*m*, 4 H); 3.08 (*d*, *J* = 4, 1 H). ^{13}C-NMR: *Table 2*. MS: 152 (5, M^+), 137 (20), 119 (22), 108 (88), 93 (67), 83 (52), 67 (100), 55 (51), 41 (76).

(−)-(1R,2R)-2,3-Epoxy-2-ethyl-6,6-dimethylbicyclo[3.1.1]heptane ((−)-**3c**). Obtained in 86% yield from (−)-**2c** according to *Procedure A*. B.p. 65°/7.6 Torr. $\alpha_D^{20} = -99.7$. IR: 2950, 1460, 1360, 1270, 905, 860. ^{1}H-NMR: 0.88 (*t*, *J* = 7, 3 H); 0.91 (*s*, 3 H); 1.19 (*s*, 3 H); 1.58 (*m*, 1 H); 1.63 (*d*, *J* = 7, 1 H); 1.78 (*m*, 2 H); 1.88 (*m*, 1 H); 2.00 (*m*, 3 H); 3.14 (*d*, *J* = 4, 1 H). ^{13}C-NMR: *Table 2*. MS: 166 (1, M^+), 151 (28), 137 (19), 123 (40), 109 (39), 97 (39), 81 (100), 67 (72), 57 (47), 41 (70).

(−)-(1R,2R)-2,3-Epoxy-6,6-dimethyl-2-propylbicyclo[3.1.1]heptane ((−)-**3d**). Obtained in 93% yield from (−)-**2d** according to *Procedure A*. B.p. 100°/0.2 Torr. $\alpha_D^{20} = -90.13$. IR: 2940, 1470, 860. ^{1}H-NMR: 0.91 (*t*, *J* = 7, 3 H); 0.93 (*s*, 3 H); 1.29 (*s*, 3 H); 1.4 (*m*, 3 H); 1.62 (*d*, *J* = 8, 1 H); 1.73 (*m*, 2 H); 1.90 (*m*, 1 H); 2.0 (*m*, 3 H); 3.11 (*d*, *J* = 4, 1 H). ^{13}C-NMR: *Table 2*. MS: 180 (3, M^+), 165 (13), 147 (14), 136 (23), 121 (20), 111 (31), 107 (55), 95 (67), 91 (56), 81 (46), 69 (82), 55 (65), 41 (100).

(−)-(1R,2R)-2-Butyl-2,3-epoxy-6,6-dimethylbicyclo[3.1.1]heptane ((−)-**3e**). Obtained in 88% yield from (−)-**2e** according to *Procedure A*. B.p. 144°/0.1 Torr. $\alpha_D^{20} = -70.9$. IR: 2940, 1465, 865. ^{1}H-NMR: 0.89 (*t*, *J* = 7, 3 H); 0.93 (*s*, 3 H); 1.29 (*s*, 3 H); 1.32 (*m*, 3 H); 1.42 (*m*, 2 H); 1.62 (*d*, *J* = 8, 1 H); 1.73 (*m*, 2 H); 1.89 (*m*, 1 H); 2.00 (*m*, 3 H); 3, 11 (*d*, *J* = 4, 1 H). ^{13}C-NMR: *Table 2*. MS: 194 (4, M^+), 176 (8), 161 (6), 150 (20), 131 (18), 125 (32), 108 (78), 95 (62), 91 (48), 81 (49), 69 (100), 55 (61), 41 (57).

(−)-(1R,2R)-2,3-Epoxy-6,6-dimethylbicyclo[3.1.1]heptane-2-ethanol ((−)-**3f**). Obtained in 86% yield from (−)-**2f** according to *Procedure A*. B.p. 82°/0.01 Torr. $\alpha_D^{20} = -98$. IR: 3300, 2960, 2900, 1460, 1160, 850. ^{1}H-NMR: 0.93 (*s*, 3 H); 1.30 (*s*, 3 H); 1.62 (*d*, *J* = 8, 1 H); 1.77 (*m*, 1 H); 1.80 (*t*, *J* = 7, 1 H); 1.84 (*t*, *J* = 7, 1 H); 1.94 (*m*, 1 H); 2.05 (*m*, 3 H); 2.63 (br. *s*, OH); 3.35 (*d*, *J* = 4, 1 H); 3.69 (*t*, *J* = 7, 2 H). ^{13}C-NMR: *Table 2*. MS: 182 (0, M^+), 164 (7), 149 (12), 138 (20), 121 (43), 107 (56), 95 (56), 91 (75), 79 (69), 67 (61), 55 (55), 41 (100).

(−)-(1R,2R)-2,3-Epoxy-6,6-dimethylbicyclo[3.1.1]heptane-2-ethyl Acetate ((−)-**3g**). Obtained in 83% yield from (−)-**2g** according to *Procedure A*. B.p. 52°/0.05 Torr. $\alpha_D^{20} = -77.4$. IR: 2900, 1720, 1430, 1360, 1240, 1030, 860. ^{1}H-NMR: 0.95 (*s*, 3 H); 1.3 (*s*, 3 H); 1.63 (*d*, *J* = 8, 1 H); 1.75 (*m*, 1 H); 1.86 (*m*, 1 H); 1.92 (*m*, 1 H); 2.04 (*s*, 3 H); 2.05 (*m*, 4 H); 3.16 (*d*, *J* = 4, 1 H); 4.06 (*m*, 1 H); 4.36 (*m*, 1 H). ^{13}C-NMR: *Table 2*. MS: 224 (0, M^+), 181 (3), 164 (8), 149 (20), 131 (24), 120 (67), 105 (43), 95 (40), 79 (30), 67 (32), 55 (28), 43 (100).

(−)-(1R,2R)-2,3-Epoxy-2-(2-methoxyethyl)-6,6-dimethylbicyclo[3.1.1]heptane ((−)-**3h**). Obtained in 87% yield from (−)-**2h** according to *Procedure A*. B.p. 85°/10 Torr. $\alpha_D^{20} = -84$. IR: 2970, 2910, 1460, 1120. ^{1}H-NMR: 0.95 (*s*, 3 H); 1.30 (*s*, 3 H); 1.62 (*d*, *J* = 8, 1 H); 0.72 (*m*, 1 H); 1.82 (*m*, 1 H); 1.90 (*m*, 1 H); 2.01 (*m*, 4 H); 3.15 (*d*, *J* = 4, 1 H); 3.30 (*s*, 3 H); 3.42 (*t*, *J* = 7, 2 H). ^{13}C-NMR: *Table 2*. MS: 196 (1, M^+), 181 (4), 152 (12), 121 (15), 107 (41), 94 (41), 91 (30), 79 (25), 67 (20), 55 (18), 45 (100), 41 (33).

(−)-(1R,2R)-2,3-Epoxy-6,6-dimethylbicyclo[3.1.1]heptane-2-ethyl 4-Toluenesulfonate ((−)-**3i**). Obtained in 85% yield from (−)-**2i** according to *Procedure A*. $\alpha_D^{20} = -67.4$ (*c* = 1.8, CCl_4). IR (CCl_4): 2900, 1360, 1180, 1160, 850. ^{1}H-NMR (CCl_4): 0.92 (*s*, 3 H); 1.28 (*s*, 3 H); 1.56 (*m*, 1 H); 1.69 (*m*, 1 H); 1.8–1.96 (*m*, 5 H); 2.03 (*m*, 1 H); 2.45 (*s*, 3 H); 3.00 (*d*, *J* = 4, 1 H); 3.95 (*m*, 2 H); 7.3 (*d*, *J* = 7, 2 H); 7.71 (*d*, *J* = 7, 2 H). ^{13}C-NMR: *Table 2*. MS: 336 (0, M^+), 200 (5), 182 (10), 164 (18), 131 (47), 121 (55), 105 (98), 91 (100), 79 (69), 43 (87).

(−)-(1R,2R)-2,3-Epoxy-6,6-dimethyl-2-vinylbicyclo[3.1.1]heptane ((−)-**3j**). Obtained in 37% yield from (−)-**2j** according to *Procedure A*. B.p. 64°/8 Torr. $[\alpha]_D^{20} = -116.2$ (*c* = 4, $CHCl_3$). IR: 3100, 2900, 1640, 1460, 1380,

1360, 1260, 910, 860. ^{1}H-NMR: 0.89 (*s*, 3 H); 1.34 (*s*, 3 H); 1.70 (*d*, *J* = 8,1 H); 0.77 (*m*, 1 H); 1.96 (*m*, 1 H); 2.08 (*m*, 2 H); 2.34 (*t*, *J* = 7, 1 H); 3.17 (*d*, *J* = 4, 1H); 5.24 (*d*, *J* = 11, 1 H); 5.26 (*d*, *J* = 18, 1 H); 5.74 (*dd*, *J* = 11, 18, 1 H). ^{13}C-NMR: *Table 2*. MS: 164 (3, M^+), 149 (16), 131 (7), 121 (37), 105 (21), 93 (27), 79 (58), 67 (36), 55 (41), 41 (100), 39 (95).

(−)-(1′R,2′R)-4-(2′,3′-Epoxy-6′,6′-dimethylbicyclo[3.1.1]hept-2′-yl)butan-2-one ((−)-**3k**). Obtained in 90% yield from (−)-**2k** according to *Procedure A*. B.p. 100°/1 Torr. $\alpha_D^{20} = -71.6$. IR: 2900, 1715, 1420, 1350, 1160, 925, 865. ^{1}H-NMR: 0.94 (*s*, 3 H); 1.29 (*s*, 3 H); 1.60 (*d*, *J* = 8, 1 H); 1.77 (*m*, 2 H); 1.90 (*m*, 1 H); 2.03 (*m*, 4 H); 2.16 (*s*, 3 H); 2.48 (*m*, 2 H); 3.09 (*d*, *J* = 4, 1 H). ^{13}C-NMR: *Table 2*. MS: 208 (2, M^+), 193 (4), 165 (9), 150 (8), 135 (9), 107 (12), 95 (11), 81 (18), 67 (15), 55 (12), 43 (100).

(−)-Ethyl (1R,2R)-2,3-Epoxy-6,6-dimethylbicyclo[3.1.1]heptane-2-propanoate ((−)-**3l**). Obtained in 82% yield from (−)-**2l** according to *Procedure A*. $\alpha_D^{20} = -63$. IR: 2950, 2900, 1720, 1460, 1440, 1360, 1160. ^{1}H-NMR: 0.94 (*s*, 3 H); 1.25 (*t*, *J* = 7, 3 H); 1.30 (*s*, 3 H); 1.61 (*m*, 1 H); 1.76 (*m*, 1 H); 1.87 (*m*, 2 H); 2.00 (*m*, 3 H); 2.10 (*m*, 1 H); 2.32 (*m*, 2 H); 3.12 (*d*, *J* = 4, 1 H); 4.13 (*q*, *J* = 7, 2 H). ^{13}C-NMR: *Table 2*. MS: 238 (1, M^+), 220 (9), 205 (10), 194 (41), 169 (29), 149 (49), 131 (63), 121 (71, 107 (95), 95 (77), 91 (90), 79 (90), 79 (68), 55 (84), 41 (100).

(−)-(1R,2S)-2,3-Epoxy-2-(methoxymethyl)-6,6-dimethylbicyclo[3.1.1]heptane ((−)-**3m**). Obtained in 68% yield from (−)-**2m** according to *Procedure A*. B.p. 31°/0.19 Torr. $\alpha_D^{20} = -84$. IR: 2950, 2790, 1450, 1180, 1100. ^{1}H-NMR: 0.94 (*s*, 3 H); 1.31 (*s*, 3 H); 1.68 (*d*, *J* = 8, 1 H); 1.76 (*m*, 1 H); 1.93 (*m*, 1 H); 2.05 (*m*, 2 H); 2.15 (*t*, *J* = 5, 1 H); 5.26 (*d*, *J* = 4, 1 H); 3.33 (*d*, *J* = 11, 1 H); 3.37 (*s*, 3 H); 3.69 (*d*, *J* = 11, 1 H): ^{13}C-NMR: *Table 2*. MS: 182 (2, M^+), 164 (5), 150 (30), 138 (35), 123 (53), 107 (58), 91 (100), 81 (68), 67 (46), 55 (37), 45 (94), 41 (70).

(−)-(1R,2S)-2,3-Epoxy-2-(ethoxymethyl)-6,6-dimethylbicyclo[3.1.1]heptane ((−)-**3n**). Obtained in 79% yield from (−)-**2n** according to *Procedure A*. B.p. 40°/0.18 Torr. $\alpha_D^{20} = -79.5$. IR: 2940, 2900, 2850, 1460, 1430, 1260, 1100, 1080, 850. ^{1}H-NMR: 0.94 (*s*, 3 H); 1.19 (*t*, *J* = 7, 3 H); 1.31 (*s*, 3 H); 1.68 (*t*, *J* = 8, 1 H); 1.75 (*m*, 1 H); 1.92 (*m*, 1 H); 2.04 (*m*, 2 H); 2.18 (*m*, 1 H); 3.24 (*d*, *J* = 4, 1 H); 3.37 (*d*, *J* = 14, 1 H); 5.50 (*m*, 2 H); 3.73 (*d*, *J* = 14, 1 H). ^{13}C-NMR: *Table 2*. MS: 196 (2, M^+), 181 (6), 150 (35), 137 (40), 127 (23), 119 (24), 107 (62), 91 (100), 81 (85), 67 (40), 55 (41), 41 (68).

(−)-Methyl (1R,2R)-2,3-Epoxy-6,6-dimethylbicyclo[3.1.1]heptane-2-butanoate ((−)-**3o**). Obtained in 93% yield from (−)-**2o** according to *Procedure A*. B.p. 120°/0.4 Torr. $\alpha_D^{20} = -73.7$. IR: 2920, 1735, 1430, 1160. ^{1}H-NMR: 0.92 (*s*, 3 H); 1.30 (*s*, 3 H); 1.48 (*m*, 1 H); 1.61 (*d*, *J* = 9, 1 H); 1.72 (*m*, 4 H); 1.90 (*m*, 1 H); 2.02 (*m*, 3 H); 2.23 (*t*, *J* = 7, 2 H); 3.12 (*d*, *J* = 4, 1 H); 3.67 (*s*, 3 H). ^{13}C-NMR: *Table 2*. MS: 238 (3, M^+), 194 (27), 163 (38), 137 (67), 121 (68), 107 (67), 95 (100), 91 (77), 79 (77), 67 (86), 55 (82), 41 (97).

(+)-(1R)-2,2-Dimethylcyclopent-3-ene-1-acetaldehyde ((+)-**4a**). Obtained in 75% yield from (−)-**3a** according to *Procedure B*. B.p. 71°/15 Torr. $\alpha_D^{20} = +18.2$. IR: 2920, 1720. ^{1}H-NMR: 0.85 (*s*, 3 H); 1.09 (*s*, 3 H); 2.03 (*m*, 1 H); 2.27 (*m*, 1 H); 2.38 (*m*, 1 H); 2.57 (*m*, 2 H); 5.57 (*m*, 2 H); 9.82 (*t*, *J* = 2, 1 H). ^{13}C-NMR: *Table 3*. MS: 138 (11, M^+), 123 (6), 105 (10), 94 (100), 79 (73), 67 (41), 55 (20), 39 (33).

(+)-(1R)-2,2-3-Trimethylcyclopent-3-ene-1-acetaldehyde ((+)-**4b**). Obtained in 75% yield from (−)-**3b** according to *Procedure B*. B.p. 59°/9 Torr. $\alpha_D^{20} = +9.4$. IR: 2940, 1710, 1450. ^{1}H-NMR: 0.8 (*s*, 3 H); 1.01 (*s*, 3 H); 1.63 (*s*, 3 H); 1.90 (*m*, 1 H); 2.3 (*m*, 1 H); 2.4 (*m*, 2 H); 2.53 (*m*, 1 H); 5.24 (*s*, 1 H); 9.8 (*t*, *J* = 2, 1 H). ^{13}C-NMR: *Table 3*. MS: 152 (2, M^+), 137 (3), 105 (10), 119 (5), 108 (100), 93 (62), 67 (27), 41 (20).

(+)-(1R)-3-Ethyl-2,2-dimethylcyclopent-3-ene-1-acetaldehyde ((+)-**4c**). Obtained in 64% yield from (−)-**3c** according to *Procedure B* from a 87:13 mixture of (+)-**4c** and (−)-**5b**. B.p. 66°/4.6 Torr. $[\alpha]_D^{20} = +1.52$ (*c* = 2.1, $CHCl_3$). IR: 2900, 1700, 1460, 1400, 1380, 1200, 1150, 1040. ^{1}H-NMR: 0.8 (*s*, 3 H); 1.0 (*s*, 3 H); 1.08 (*t*, *J* = 7, 3 H); 1.93 (*m*, 3 H); 2.28 (*m*, 1 H); 2.4 (*m*, 2 H); 2.53 (*m*, 1 H); 5.24 (br. *s*, 1 H); 9.81 (*t*, *J* = 2, 1 H). ^{13}C-NMR: *Table 3*. MS: 166 (1, M^+), 122 (77), 107 (100), 95 (16), 91 (21), 81 (20), 67 (17), 55 (12), 41 (29).

(+)-(1R)-2,2-Dimethyl-3-propylcyclopent-3-ene-1-acetaldehyde ((+)-**4d**). Obtained in 70% yield from (−)-**3d** according to *Procedure B*. B.p. 85°/0.1 Torr. $\alpha_D^{20} = +4.2$. IR: 2960, 1725, 1465. ^{1}H-NMR: 0.8 (*s*, 3 H); 0.95 (*t*, *J* = 7, 3 H); 1.0 (*s*, 3 H); 1.52 (*m*, 2 H); 1.89 (*m*, 3 H); 2.25 (*m*, 1 H); 2.4 (*m*, 2 H); 2.53 (*m*, 1 H); 5.24 (br. *s*, 1 H); 9.8 (*t*, *J* = 2, 1 H). ^{13}C-NMR: *Table 3*. MS: 180 (1, M^+), 136 (41), 107 (100), 95 (33), 81 (26), 67 (22), 55 (19), 41 (37).

(+)-(1R)-3-Butyl-2,2-dimethylcyclopent-3-ene-1-acetaldehyde ((+)-**4e**). Obtained in 72% yield from (−)-**3e** according to *Procedure B*. B.p. 90°/0.1 Torr. $[\alpha]_D^{20} = +6.6$ (*c* = 2.6, CCl_4). IR: 2950, 1720, 1460, 1360. ^{1}H-NMR: 0.80 (*s*, 3 H); 0.92 (*t*, *J* = 7, 3 H); 1.01 (*s*, 3 H); 1.35 (*m*, 3 H); 1.46 (*m*, 2 H); 1.91 (*m*, 2 H); 2.27 (*m*, 1 H); 2.24 (*m*, 2 H); 2.53 (*m*, 1 H); 5.25 (br. *s*, 1 H); 9.8 (*t*, *J* = 2, 1 H). ^{13}C-NMR: *Table 3*. MS: 194 (0, M^+), 150 (27), 135 (8), 121 (7), 108 (100), 95 (29), 81 (17), 67 (13), 55 (13), 41 (25).

(+)-(1R)-3-(2-Hydroxyethyl)-2,2-dimethylcyclopent-3-ene-1-acetaldehyde ((+)-**4f**). Obtained in 61% yield from (−)-**3f** according to *Procedure B*. A soln. of $LiOH \cdot H_2O$ (210 g, 5 mol) and (+)-**4g** (120 g, 0.51 mol) in H_2O (480 ml) and THF (600 ml) was vigorously stirred for 48 at r.t. The mixture was extracted with Et_2O (3 × 150 ml) and successively washed with H_2O and brine, dried (Na_2SO_4), and evaporated. Purification of the oil on a short

column (SiO_2, cyclohexane/AcOEt 85:15) gave (+)-**4f** (74.6 g, 80%). Colourless oil. $[\alpha]_D^{20} = +6.4$ ($c = 2.1$, $CHCl_3$). IR: 3350, 2900, 1720, 1040. ^{1}H-NMR: 0.78 (*s*, 3 H); 1.03 (*s*, 3 H); 1.80 (br. *s*, OH); 1.95 (*m*, 1 H); 2.25 (*m*, 3 H); 2.30 (*m*, 1 H); 2.40 (*m*, 1 H); 2.53 (*m*, 1 H); 3.80 (*m*, 2 H); 5.37 (br. *s*, 1 H); 9.80 (*t*, $J = 2$, 1 H). ^{13}C-NMR: *Table 3*. MS: 182 (0, M^+), 138 (43), 120 (20), 107 (100), 94 (50), 91 (45), 79 (33), 67 (18), 55 (16), 41 (30).

*(+)-(4*R*)-5,5-Dimethyl-4-(2-oxoethyl)cyclopent-1-ene-1-ethyl Acetate* ((+)-**4g**). Obtained in 69% yield from (−)-**3g** according to *Procedure B*. B.p. 77°/0.06 Torr. $\alpha_D^{20} = +6.1$. IR: 3920, 1720, 1450, 1370, 1220, 1020, 800. ^{1}H-NMR: 0.81 (*s*, 3 H); 1.03 (*s*, 3 H); 1.93 (*m*, 1 H); 2.05 (*s*, 3 H); 2.28 (*m*, 3 H); 2.38 (*m*, 1 H); 2.45 (*m*, 1 H); 2.55 (*m*, 1 H); 4.21 (*t*, $J = 7$, 2 H); 5.33 (br. *s*, 1 H); 9.81 (*t*, $J = 2$, 1 H). ^{13}C-NMR: *Table 3*. MS: 224 (0, M^+), 120 (100), 105 (58), 91 (17), 79 (12), 43 (49).

*(+)-(1*R*)-3-(2-Methoxyethyl)-2,2-dimethylcyclopent-3-ene-1-acetaldehyde* ((+)-**4h**). Obtained in 65% yield from (−)-**3h** according to *Procedure B*. $\alpha_D^{20} = +8.1$. IR: 2960, 1725, 1460, 1120. ^{1}H-NMR: 0.81 (*s*, 3 H); 1.02 (*s*, 3 H); 1.94 (*m*, 2 H); 2.22 (*m*, 2 H); 2.30 (*m*, 1 H); 2.40 (*m*, 1 H); 2.55 (*m*, 1 H); 3.37 (*s*, 3 H); 3.55 (*dt*, $J = 2$, 7, 2 H); 5.30 (br. *s*, 1 H); 9.80 (*t*, $J = 2$, 1 H). ^{13}C-NMR: *Table 3*. MS: 196 (0, M^+), 152 (33), 120 (20), 107 (91), 94 (100), 91 (31), 79 (26), 45 (95), 41 (23).

*(+)-(4*R*)-5,5-Dimethyl-4-(2-oxoethyl)cyclopent-1-ene-1-ethyl 4-Toluenesulfonate* ((+)-**4i**). To a soln. of TsCl (16.3 g, 85.6 mmol) in pyridine (26 ml) was added dropwise at −10° (+)-**4f** (11.4 g, 62.6 mmol). After 30 min, stirring was stopped and the mixture kept overnight at −10° before dilution with Et_2O (150 ml). The mixture was successively washed with 15% aq. HCl soln., sat. aq. $NaHCO_3$ soln., H_2O, and brine, dried (Na_2SO_4), and evaporated: unstable (+)-**4i** (18.3 g, 87%). $[\alpha]_D^{20} = +4.6$ ($c = 1.8$, $CHCl_3$). IR: 3000, 2900, 2700, 1700, 1580, 1440, 1340, 1160, 1080. ^{1}H-NMR: 0.75 (*s*, 3 H); 0.95 (*s*, 3 H); 1.87 (*m*, 1 H); 2.22 (*m*, 2 H); 2.30 (*m*, 2 H); 2.37 (*m*, 1 H); 2.46 (*s*, 3 H); 2.51 (*m*, 1 H); 4.16 (*dt*, $J = 2$, 7, 2 H); 5.21 (br. *s*, 1 H); 7.36 (*d*, $J = 7$, 2 H); 7.79 (*d*, $J = 7$, 2 H); 9.79 (*t*, $J = 2$, 1 H). ^{13}C-NMR: *Table 3*.

*(+)-(1*R*)-2,2-Dimethyl-3-vinylcyclopent-3-ene-1-acetaldehyde* ((+)-**4j**). Isolated by prep. GLC in 10% yield from a 16:64:20 mixture (+)-**4j**/(−)-**5a**/(+)-(*Z*)-**6**, obtained after isomerisation of (−)-**3j** according to *Procedure B*. $\alpha_D^{20} = +2.3$. IR: 2900, 2720, 1730. ^{1}H-NMR: 0.92 (*s*, 3 H); 1.15 (*s*, 3 H); 1.98 (*m*, 1 H); 2.34 (*m*, 1 H); 2.45 (*m*, 1 H); 2.45 (*m*, 2 H); 2.58 (*m*, 1 H); 5.04 (*d*, $J = 10$, 1 H); 5.40 (*d*, $J = 17$, 1 H); 5.71 (br. *s*, 1 H); 6.22 (*dd*, $J = 10$, 17, 1 H). MS: 164 (6, M^+), 120 (94), 105 (100), 91 (34), 79 (33), 65 (11), 55 (12), 39 (64).

*(+)-(1*R*)-2,2-Dimethyl-3-(3-oxobutyl)cyclopent-3-ene-1-acetaldehyde* ((+)-**4k**). Obtained in 35% yield from (−)-**3k** according to *Procedure B* from a 24:76 mixture (−)-**5c**/(+)-**4k**. B.p. 75°/0.03 Torr. $\alpha_D^{20} = +7.4$. IR: 2900, 1710, 1360, 1160. ^{1}H-NMR: 0.81 (*s*, 3 H); 1.03 (*s*, 3 H); 1.90 (*m*, 1 H); 2.18 (*s*, 3 H); 2.20 (*m*, 2 H); 2.28 (*m*, 1 H); 2.40 (*m*, 1 H); 2.45 (*m*, 1 H); 2.54 (*m*, 1 H); 2.64 (*t*, $J = 7$, 2 H); 5.18 (br. *s*, 1 H); 9.81 (*t*, $J = 2$, 1 H). ^{13}C-NMR: *Table 3*. MS: 208 (1, M^+), 164 (51), 135 (12), 121 (52), 106 (66), 91 (31), 43 (100).

*(+)-Ethyl (4*R*)-5,5-Dimethyl-4-(2-oxoethyl)cyclopent-1-ene-1-propanoate* ((+)-**4l**). Obtained in 67% yield from (−)-**3l** according to *Procedure B*. $[\alpha]_D^{20} = +2.5$ ($c = 3.0$, CCl_4). IR: 2940, 1720, 1150. ^{1}H-NMR: 0.82 (*s*, 3 H); 1.04 (*s*, 3 H); 1.26 (*t*, $J = 7$, 3 H); 1.90 (*m*, 1 H); 2.26 (*m*, 3 H); 2.35 (*m*, 1 H); 2.41 (*m*, 2 H); 2.50 (*m*, 2 H); 4.14 (*q*, $J = 7$, 2 H); 5.24 (*s*, 1 H); 9.80 (*t*, $J = 2$, 1 H). ^{13}C-NMR: *Table 3*. MS: 238 (0, M^+), 194 (56), 149 (19), 135 (19), 121 (72), 107 (100), 91 (51), 79 (30), 55 (30), 41 (30).

*(+)-(1*R*)-3-(Methoxymethyl)-2,2-dimethylcyclopent-3-ene-1-acetaldehyde* ((+)-**4m**). Obtained in 58% yield from (−)-**3m** according to *Procedure B*. B.p. 44°/0.15 Torr $\alpha_D^{20} = +15.9$. IR: 2900, 1700, 1440, 1350, 1080. ^{1}H-NMR: 0.89 (*s*, 3 H); 1.07 (*s*, 3 H); 1.97 (*m*, 1 H); 2.35 (*m*, 1 H); 2.43 (*m*, 1 H); 2.54 (*m*, 2 H); 3.33 (*s*, 3 H); 3.94 (*s*, 2 H); 5.59 (*s*, 1 H); 9.81 (*t*, $J = 0.5$, 1 H). ^{13}C-NMR: *Table 3*. MS: 182 (1, M^+), 167 (5), 150 (62), 138 (68), 123 (97), 106 (79), 91 (100), 79 (53), 67 (28), 45 (57).

*(+)-(1*R*)-3-(Ethoxymethyl)-2,2-dimethylcyclopent-3-ene-1-acetaldehyde* ((+)-**4n**). Obtained in 53% yield from (−)-**3n** according to *Procedure B*. B.p. 52°/0.15 Torr. $\alpha_D^{20} = +12.9$. IR: 2920, 2840, 1705, 1080. ^{1}H-NMR: 0.90 (*s*, 3 H); 1.08 (*s*, 3 H); 1.22 (*t*, $J = 7$, 3 H); 1.98 (*m*, 1 H); 2.35 (*m*, 1 H); 2.42 (*m*, 1 H); 2.54 (*m*, 2 H); 3.49 (*q*, $J = 7$, 2 H); 3.98 (*s*, 2 H); 5.60 (br. *s*, 1 H); 9.81 (*t*, $J = 1$, 1 H). ^{13}C-NMR: *Table 3*. MS: 196 (1, M^+), 181 (7), 150 (60), 137 (57), 106 (72), 91 (100), 79 (60), 67 (40), 53 (37), 41 (65).

*(+)-Methyl (4*R*)-5,5-Dimethyl-4-(2-oxoethyl)cyclopent-1-ene-1-butanoate* ((+)-**4o**). Obtained in 64% yield from (−)-**3o** according to *Procedure B* from a 85:15 mixture (+)-**4o**/(−)-**5d**. B.p. 140°/0.3 Torr. $\alpha_D^{20} = +9.8$. IR: 2950, 1720, 1420, 1350, 1200. ^{1}H-NMR: 0.80 (*s*, 3 H); 1.00 (*s*, 3 H); 1.84 (*m*, 2 H); 1.94 (*m*, 3 H); 2.30 (*m*, 1 H); 2.36 (*t*, $J = 7$, 2 H); 2.40 (*m*, 1 H); 2.50 (*m*, 2 H); 3.68 (*s*, 3 H); 5.28 (br. *s*, 1 H); 9.81 (*t*, $J = 3$, 1 H). ^{13}C-NMR: *Table 3*. MS: 238 (0, M^+), 194 (68), 120 (94), 107 (100), 91 (53), 79 (42), 67 (26), 59 (21), 55 (33), 41 (38).

*(−)-(1*S*,2*R*)-6,6-Dimethyl-2-vinylbicyclo[3.1.1]heptan-3-one* ((−)-**5a**). Obtained in 53% yield during the attempted preparation of (+)-**4j** from (−)-**3j** according to *Procedure B*. Purified by chromatography (SiO_2, cyclohexane/AcOEt 9:1). $\alpha_D^{20} = -49.5$. IR: 2920, 1710, 1640, 1460, 1400, 1035, 910. ^{1}H-NMR: 0.93 (*s*, 3 H); 1.27 (*d*, $J = 8$, 1 H); 1.37 (*s*, 3 H); 2.14 (*m*, 1 H); 2.19 (*dt*, $J = 2$, 7, 1 H); 2.47 (*m*, 1 H); 2.53 (*m*, 1 H); 2.69 (*m*, 1 H); 3.27 (*m*,

1 H); 5.07 (*d*, *J* = 15, 1 H); 5.17 (*d*, *J* = 11, 1 H); 5.88 (*ddd*, *J* = 7, 11, 15, 1 H). ^{13}C-NMR: *Table 6*. MS: 164 (3, M^{+}), 149 (2), 136 (3), 122 (11), 107 (9), 95 (34), 79 (30), 69 (58), 53 (14), 41 (100).

(−)-(1S,2R)-2-Ethyl-6,6-dimethylbicyclo[3.1.1]heptan-3-one ((−)-**5b**). Isolated in 6% yield during the purification of (+)-**4c**. $[\alpha]_D^{20} = -12.6$ (*c* = 1.1, $CHCl_3$). IR: 2950, 1700, 1200. ^{1}H-NMR: 0.89 (*s*, 3 H); 0.92 (*t*, *J* = 7, 3 H); 1.17 (*d*, *J* = 9, 1 H); 1.32 (*m*, 1 H); 1.35 (*s*, 3 H); 1.89 (*m*, 1 H); 2.10 (*d*, *J* = 5, 2 H); 2.35 (*m*, 1 H); 2.40 (*d*, *J* = 18, 1 H); 2.43 (*m*, 1 H); 2.63 (*d*, *J* = 18, 1 H). ^{13}C-NMR: *Table 6*. MS: 166 (9, M^{+}), 97 (86), 81 (23), 69 (100), 55 (63), 41 (75).

(−)-(1S,2R)-6,6-Dimethyl-2-(3-oxobutyl)bicyclo[3.1.1]heptan-3-one ((−)-**5c**). Isolated in 18% yield during the purification of (+)-**4k**. $[\alpha]_D^{20} = -13$ (*c* = 4.4, $CHCl_3$). IR: 2920, 1705, 1360, 1160. ^{1}H-NMR: 0.87 (*s*, 3 H); 1.20 (*d*, *J* = 8, 1 H); 1.34 (*s*, 3 H); 1.57 (*m*, 1 H); 2.00 (*m*, 2 H); 2.10 (*m*, 1 H); 2.16 (*s*, 3 H); 2.44 (*m*, 2 H); 2.60 (*m*, 4 H). ^{13}C-NMR: *Table 6*. MS: 208 (9, M^{+}), 165 (5), 139 (20), 93 (10), 81 (11), 69 (14), 43 (100).

(−)-Methyl (1S,2R)-4-(3-Oxo-6,6-dimethylbicyclo[3.1.1]hept-2-yl)butanoate ((−)-**5d**). Isolated in 6% yield during the preparation of (+)-**4o**. $[\alpha]_D^{20} = -42.3$ (*c* = 1.3, $CHCl_3$). IR: 3040, 1730, 1705, 1455, 1425, 1360, 1160. ^{1}H-NMR: 0.89 (*s*, 3 H); 1.17 (*d*, *J* = 9, 1 H); 1.35 (*s*, 3 H); 1.36 (*m*, 1 H); 1.60 (*m*, 1 H); 1.70 (*m*, 1 H); 1.80 (*m*, 1 H); 2.10 (*m*, 2 H); 2.32 (*q*, *J* = 7, 2 H); 2.35 (*m*, 1 H); 2.45 (*m*, 1 H); 2.47 (*m*, 1 H); 2.63 (*m*, 1 H); 3.67 (*s*, 3 H). ^{13}C-NMR: *Table 6*. MS: 238 (4, M^{+}), 207 (4), 169 (48), 137 (35), 109 (40), 95 (100), 81 (64), 69 (77), 55 (29), 41 (49).

(+)-(1R,Z)-2-Ethylidene-6,6-dimethylbicyclo[3.1.1]heptan-3-one ((+)-(*Z*)-**6**). Isolated by prep. GLC in 8% yield from a 16:64:20 mixture from (−)-**3j** according to *Procedure B*. $[\alpha]_D^{20} = +69.5$ (*c* = 0.2, $CHCl_3$). IR: 2900, 1700, 1620, 1060. ^{1}H-NMR: 0.82 (*s*, 3 H); 1.25 (*d*, *J* = 7, 1 H); 1.35 (*s*, 3 H); 1.62 (*s*, 1 H); 2.15 (*d*, *J* = 7, 3 H); 2.45–2.65 (*m*, 4 H); 5.74 (*q*, *J* = 7, 1 H). ^{13}C-NMR: *Table 6*. MS: 164 (10, M^{+}), 149 (4), 121 (53), 95 (100), 67 (98), 41 (34).

(+)-(1R,E)-2-Ethylidene-6,6-dimethylbicyclo[3.1.1]heptan-3-one ((+)-(*E*)-**6**). (−)-**5a** (400 mg, 2.44 mmol) was stirred at r.t. in a 5% soln. of MeONa/MeOH (20 ml) during 5 h. The solvent was then evaporated, the mixture diluted with H_2O (20 ml) and extracted with Et_2O (4 × 20 ml). The org. phase was successively washed with H_2O (4 × 20 ml) and brine, dried (Na_2SO_4), and evaporated: pure (+)-(*E*)-**6** after bulb-to-bulb distillation (360 mg, 90%). $[\alpha]_D^{20} = +71$ (*c* = 5.5, $CHCl_3$). IR: 2900, 1700, 1620, 1440, 1280, 1230, 1060, 960, 830. ^{1}H-NMR: 0.80 (*s*, 3 H); 1.24 (*d*, *J* = 8, 1 H); 1.40 (*s*, 3 H); 1.70 (*d*, *J* = 7, 3 H); 2.20 (*m*, 1 H); 2.52 (*dd*, *J* = 3, 18, 1 H); 2.66 (*m*, 1 H); 2.70 (*m*, 1 H); 2.99 (*t*, *J* = 7, 1 H); 6.72 (*q*, *J* = 7, 1 H). ^{13}C-NMR: *Table 6*. MS: 164 (32, M^{+}), 149 (5), 121 (32), 107 (19), 95 (100), 91 (13), 77 (15), 67 (98), 53 (12), 41 (77).

(−)-(1R)-2-(2-Iodoethyl)-6,6-dimethylbicyclo[3.1.1]hept-2-ene ((−)-**7a**). To a soln. of EtMgI (EtI (6.3 g, 40 mmol) and Mg (1 g, 41 mmol)) in Et_2O (50 ml) was added dropwise at 0° a soln. of (−)-**2i** (10 g, 31.2 mmol) in Et_2O (20 ml). After 1 h at r.t., the reaction was quenched with sat. aq. NH_4Cl soln. (35 ml), diluted with H_2O, and extracted with Et_2O (4 × 50 ml). The org. phases were successively washed with H_2O and brine, dried (Na_2SO_4), and evaporated. The crude oil (8.1 g) was purified by bulb-to-bulb distillation to give (−)-**7a** (7.98, 93%). Colourless oil. B.p. 130°/0.2 Torr. $\alpha_D^{20} = -27.1$. IR: 2940, 1470, 1440, 1370, 1240, 1180. ^{1}H-NMR: 0.84 (*s*, 3 H); 1.18 (*d*, *J* = 8, 1 H); 1.27 (*s*, 3 H); 2.00 (*t*, *J* = 5, 1 H); 2.08 (*m*, 1 H); 2.21 (*m*, 2 H); 2.37 (*dt*, *J* = 6, 8, 1 H); 2.54 (*t*, *J* = 7, 2 H); 3.14 (*dt*, *J* = 3, 8, 2 H); 5.30 (br. *s*, 1 H). ^{13}C-NMR: *Table 1*. MS: 276 (1, M^{+}), 233 (3), 155 (18), 105 (100), 91 (20), 79 (18), 41 (15).

(−)-(1R)-6,6-Dimethylbicyclo[3.1.1]hept-2-ene-2-propanol ((−)-**7b**). Obtained in 65% yield from (−)-**2l** according to the procedure used for (+)-**14c**. B.p. 68°/0.2 Torr. $\alpha_D^{20} = -41.2$. IR: 3300, 2900, 1460, 1440, 1350, 1050. ^{1}H-NMR: 0.84 (*s*, 3 H); 1.34 (*d*, *J* = 8, 1 H); 1.27 (*s*, 3 H); 1.55 (br. *s*, OH); 1.63 (*m*, 2 H); 2.02 (*t*, *J* = 7, 3 H); 2.08 (*m*, 1 H); 2.21 (*m*, 2 H); 2.37 (*dt*, *J* = 5, 8, 1 H); 3.64 (*t*, *J* = 7, 2 H); 5.22 (br. *s*, 1 H). ^{13}C-NMR: *Table 1*. MS: 180 (4, M^{+}), 136 (12), 119 (25), 105 (17), 91 (100), 79 (23), 41 (21).

(−)-(1R)-2-(3'-Methoxypropyl)-6,6-dimethylbicyclo[3.1.1]hept-2-ene ((−)-**7c**). Obtained in 72% yield from (−)-**7b** according to the procedure used for (−)-**2n**. B.p. 34°/0.2 Torr. $\alpha_D^{20} = -26.6$. IR: 2900, 1440, 1370, 1350, 1100. ^{1}H-NMR: 0.83 (*s*, 3 H); 1.14 (*d*, *J* = 8, 1 H); 1.27 (*s*, 3 H); 1.62 (*m*, 2 H); 1.99 (*m*, 3 H); 2.08 (*m*, 1 H); 2.21 (*m*, 2 H); 2.14 (*dt*, *J* = 5, 8, 1 H); 3.33 (*s*, 3 H); 3.37 (*t*, *J* = 7, 2 H); 5.20 (br. *s*, 1 H). ^{13}C-NMR: *Table 1*. MS: 194 (1, M^{+}), 162 (4), 147 (8), 136 (20), 119 (32), 105 (17), 91 (100), 79 (20), 41 (18).

(−)-(1R)-6,6-Dimethylbicyclo[3.1.1]hept-2-ene-2-propyl 4-Toluenesulfonate ((−)-**7d**). Obtained in 97% yield from (−)-**7b** according to the procedure used for (+)-**4i**. $[\alpha]_D^{20} = -18$ (*c* = 1.8, $CHCl_3$). IR: 2900, 1600, 1360, 1160, 950, 810. ^{1}H-NMR: 0.75 (*s*, 3 H); 1.04 (*d*, *J* = 8, 1 H); 1.24 (*s*, 3 H); 1.69 (*m*, 2 H); 1.95 (*m*, 3 H); 2.05 (*m*, 1 H); 2.15 (*m*, 2 H); 2.30 (*dt*, *J* = 5, 8, 1 H); 2.45 (*s*, 3 H); 4.01 (*s*, 2 H); 5.08 (br. *s*, 1 H); 7.35 (*d*, *J* = 8, 2 H); 7.79 (*d*, *J* = 8, 2 H). ^{13}C-NMR: *Table 1*. MS: 334 (0, M^{+}), 198 (3), 190 (8), 155 (22), 119 (14), 91 (100), 79 (15), 65 (17), 41 (12).

(−)-(1R)-6,6-Dimethylbicyclo[3.1.1]hept-2-ene-2-propanal ((−)-**7e**). Obtained in 82% yield from (−)-**7b** according to the procedure used for (−)-**2k**. B.p. 87°/4 Torr. $\alpha_D^{20} = -31.1$. IR: 2900, 1720. ^{1}H-NMR: 0.82 (*s*, 3 H); 1.14 (*d*, *J* = 8, 1 H); 1.27 (*s*, 3 H); 2.00 (*t*, *J* = 6, 1 H); 2.09 (*m*, 1 H); 2.21 (*m*, 2 H); 2.30 (*m*, 2 H); 2.36 (*dt*, *J* = 5, 8,

1 H); 2.48 (*m*, 2 H); 5.22 (br. *s*, 1 H); 9.76 (*t*, *J* = 2, 1 H). ^{13}C-NMR: *Table 1*. MS: 178 (2, $M^{+\cdot}$), 134 (15), 117 (22), 105 (17), 91 (100), 79 (21), 41 (21).

(−)-(1R)-4-(6,6-Dimethylbicyclo[3.1.1]hept-2-enyl)butan-2-ol ((−)-**8**). To a suspension of Mg powder (350 mg, 14.6 mmol) in Et_2O (5 ml) under reflux was added dropwise a soln. of (−)-**7a** (4 g, 14.5 mmol) in Et_2O (15 ml). After disappearance of the Mg, a soln. of acetaldehyde (640 mg, 14.5 mmol) in Et_2O (5 ml) was added at 0° and the mixture stirred for 2 h at r.t. The reaction was quenched with sat. aq. NH_4Cl soln. (30 ml), diluted with H_2O (30 ml), and extracted with Et_2O (3 × 20 ml). The org. phase was successively washed with H_2O and brine, dried (Na_2SO_4), and evaporated. The crude oil (2.8 g) was purified by chromatography (SiO_2, 245 g, cyclohexane/AcOEt 9:1) to give (−)-**8** (1.68 g, 60%; 1:1 mixture of diastereoisomers). Colourless oil. $[\alpha]_D^{20} = -26.84$ (*c* = 1.5, CCl_4). IR: 3300, 2900, 1200. ^{1}H-NMR: 0.82 (*s*, 1.5 H); 0.83 (*s*, 1.5 H); 1.04 (*d*, *J* = 8, 0.5 H); 1.05 (*d*, *J* = 8, 0.5 H); 1.18 (*d*, *J* = 7, 1.5 H); 1.19 (*d*, *J* = 7, 1.5 H); 1.28 (*s*, 3 H); 1.50 (*m*, 3 H); 2.02 (*m*, 2 H); 2.08 (*m*, 2 H); 2.22 (*m*, 2 H); 2.36 (*m*, 1 H); 3.80 (*m*, 1 H); 5.23 (*s*, 1 H). MS: isomer A: 194 (0, $M^{+\cdot}$), 136 (13), 119 (18), 105 (17), 91 (100), 79 (20), 43 (23); isomer B: 194 (0, $M^{+\cdot}$), 161 (4), 136 (13), 119 (15), 105 (20), 91 (100), 77 (18), 41 (20).

(−)-(1R)-4-(6,6-Dimethylbicyclo[3.1.1]hept-2-en-2-yl)-2-methylbutan-2-ol ((−)-**9**). Obtained in 94% yield ($\alpha_D^{20} = -25.1$) from (−)-**2k** by a *Grignard* mono-addition. Obtained in 87% yield ($\alpha_D^{20} = -24.4$) from (−)-**21** by a *Grignard* di-addition B.p. 50°/0.17 Torr. IR: 3300, 2960, 1480, 1400, 1380, 1220, 1160, 925. ^{1}H-NMR: 0.83 (*s*, 3 H); 1.05 (*d*, *J* = 8, 1 H); 1.22 (*s*, 6 H); 1.28 (*s*, 3 H); 1.51 (*dt*, *J* = 3, 5, 2 H); 2.01 (*m*, 4 H); 2.08 (*m*, 1 H); 2.22 (*m*, 2 H); 2.37 (*dt*, *J* = 5, 8, 1 H); 5.22 (br. *s*, 1 H). ^{13}C-NMR: *Table 1*. MS: 208 (0, $M^{+\cdot}$), 190 (4), 175 (7), 147 (12), 134 (16), 119 (35), 105 (30), 91 (100), 79 (18), 69 (16), 59 (15), 41 (24).

(−)-(1S,2R,6S,8S)-3,3,8-trimethyl-7,11-dioxatetracyclo[6.2.1.1^{2,4}.0^{1,6}]dodecane ((−)-**11**). A soln. of (−)-**3k** (2.08 g, 10 mmol) and TsOH (19 mg, 0.1 mmol) in cyclohexane (10 ml) was refluxed for 3 h. The crude soln. was passed through a chromatography column (SiO_2, 80 g, cyclohexane/AcOEt 9:1) to afford (−)-**11** (1.62 g, 78%). $\alpha_D^{20} = -67.2$. IR: 2970, 1200. ^{1}H-NMR: 1.01 (*s*, 3 H); 1.35 (*s*, 3 H); 1.63 (*s*, 3 H); 1.57–2.1 (*m*, 1 H); 2.25–2.35 (*m*, 1 H); 4.12 (*dd*, *J* = 11, 4, 1 H). ^{13}C-NMR: 18.9 (*Me*–C(8)); 24.2 (Me '*syn*' to C(6)); 27.8 (Me '*anti*' to C(6)); 29.7 (C(12)); 33.9 (C(5)); 35.2, 37.3 (C(9), C(10)); 39.6 (C(3)); 42.6 (C(4)); 46.2 (C(2)); 74.6 (C(6)); 90.0 (C(1)); 107.5 (C(8)). MS: 208 (4, $M^{+\cdot}$), 165 (8), 138 (41), 121 (12), 110 (51), 105 (47), 95 (36), 81 (25), 43 (100).

(+)-(1R,3S)-6,6-Dimethylspiro[bicyclo[3.1.1]heptane-2,1'-cyclopropan]-3-yl Acetate ((+)-**12**). When (−)-**7a** was treated according to *Procedure A*, (+)-**12** was isolated (11%) beside (−)-**2g** (13%) and (−)-**3g** (9%) by chromatography (SiO_2, cyclohexane/AcOEt 4:1). $\alpha_D^{20} = +73.8$. IR: 2900, 1720, 1460, 1350, 1240, 1140, 1000. ^{1}H-NMR: 0.18 (*m*, 1 H); 0.4 (*m*, 1 H); 0.48 (*m*, 1 H); 0.71 (*m*, 1 H); 0.96 (*s*, 3 H); 1.09 (*t*, *J* = 5, 1 H); 1.21 (*s*, 3 H); 1.71 (*d*, *J* = 8, 1 H); 1.76 (*dd*, *J* = 3, 15, 1 H); 1.93 (*m*, 1 H); 1.97 (*s*, 3 H); 2.26 (*m*, 1 H); 2.41 (*m*, 1 H); 4.67 (*d*, *J* = 7, 1 H). ^{13}C-NMR: 9.2 (C(2')); 16.1 (C(3')); 21.5 (*Me*COO); 21.7 (Me_{endo}–C(6)); 25.4 (C(2)); 26.3 (Me_{exo}–C(6)); 27.7 (C(7)); 34.2 (C(4)); 39.8 (C(5)); 40.7 (C(6)); 50.6 (C(1)); 74.0 (C(3)); 170.7 (MeCOO). MS: 208 (0, $M^{+\cdot}$), 166 (6), 148 (25), 133 (43), 105 (91), 91 (40), 79 (30), 69 (25), 43 (100).

(+)-(1R)-2,2-Dimethyl-3-methylidenecyclopentane-1-acetaldehyde ((+)-**13**). A soln. of (+)-**4f** (58 g, 0.32 mol) in toluene (160 ml) was passed (25 ml/h, N_2 60 ml/min) through a 5-m *Pyrex* column at 480°. The condensed material was distilled through a 10-cm *Vigreux* column: (+)-**13** (34.5 g, 71%). Colourless oil. B.p. 32°/0.08 Torr. $\alpha_D^{20} = +2.5$. IR: 2900, 1720, 1460, 1360, 880. ^{1}H-NMR: 0.85 (*s*, 3 H); 1.08 (*s*, 3 H); 1.35 (*m*, 1 H); 1.92 (*m*, 1 H); 2.05 (*m*, 1 H); 2.27 (*m*, 1 H); 2.37 (*m*, 1 H); 2.50 (*m*, 2 H); 4.80 (*d*, *J* = 7, 2 H); 9.81 (*t*, *J* = 2, 1 H). ^{13}C-NMR: *Table 3*. MS: 152 (0, $M^{+\cdot}$), 119 (5), 108 (100), 93 (73), 81 (21), 67 (49), 53 (20), 41 (68), 39 (53).

(+)-2,2,3-Trimethylcyclopent-3-ene-1-ethanol ((+)-**14a**). Obtained in 97% yield from (+)-**4b** according to procedure used for (+)-**14c**. B.p. 97°/10 Torr. $\alpha_D^{20} = +4.57$, $[\alpha]_D^{20} = +3.1$ (*c* = 8, CCl_4). IR: 3300, 3040, 2950, 1460, 1440, 1050. ^{1}H-NMR: 0.78 (*s*, 3 H); 0.98 (*s*, 3 H); 1.55 (*m*, 1 H); 1.61 (*s*, 3 H); 1.73 (*m*, 1 H); 1.83 (*m*, 2 H); 2.0 (br. *s*, OH); 2.27 (*m*, 1 H); 3.67 (*m*, 2 H); 5.22 (br. *s*, 1 H). ^{13}C-NMR: *Table 4*. MS: 154 (5, $M^{+\cdot}$), 139 (12), 136 (8), 121 (29), 105 (19), 95 (100), 93 (41), 79 (20), 67 (18), 41 (20).

(−)-(1R)-2,2,3-Trimethylcyclopent-3-ene-1-ethyl Acetate ((−)-**14b**). Obtained in 87% yield from (+)-**14a** according to the procedure used for (−)-**14d**. B.p. 113°/12 Torr. $\alpha_D^{20} = -2.3$; $[\alpha]_D^{20} = -0.63$ (*c* = 8, CCl_4). IR: 2950, 1730, 1450, 1360, 1240, 1040. ^{1}H-NMR: 0.78 (*s*, 3 H); 0.99 (*s*, 3 H); 1.57 (*m*, 1 H); 1.61 (*s*, 3 H); 1.80 (*m*, 3 H); 2.06 (*s*, 3 H); 2.30 (*m*, 1 H); 4.10 (*m*, 2 H); 5.23 (br. *s*, 1 H). ^{13}C-NMR: *Table 4*. MS: 196 (4, $M^{+\cdot}$), 136 (36), 121 (100), 108 (68), 93 (75), 79 (26), 43 (59).

(+)-(1R)-3-Ethyl-2,2-dimethylcyclopent-3-ene-1-ethanol ((+)-**14c**). To a suspension of $LiAlH_4$ (40 g, 0.92 mol) in refluxing Et_2O (3 l) was added dropwise a soln. of (+)-**4c** (403 g, 2.43 mol) in Et_2O (1 l) during 2 h. After 1 h at r.t., the mixture was cooled to 0°, and H_2O (40 ml), 15% aq. NaOH soln. (40 ml), and then H_2O (120 ml) were cautiously added. After 30 min, the mixture was filtered over *Celite* and evaporated: crude oil (426 g). Distillation over a *Vigreux* column (30 cm) gave pure (+)-**14c** (327.8 g, 80%). B.p. 76°/5 Torr. $\alpha_D^{20} = +4.9$. IR: 3400, 3000, 1490, 1090. ^{1}H-NMR: 0.78 (*s*, 3 H); 0.99 (*s*, 3 H); 1.06 (*t*, *J* = 7, 3 H); 1.53 (*m*, 1 H); 1.73 (*m*, 1 H); 1.77 (*m*, OH); 1.85 (*m*,

2 H); 1.94 (*m*, 2 H); 2.32 (*m*, 1 H); 3.67 (*m*, 2 H); 5.23 (br. *s*, 1 H). ^{13}C-NMR: *Table 4*. MS: 168 (9, M^{+}), 153 (11), 135 (18), 121 (18), 109 (100), 95 (43), 79 (22), 41 (21).

(−)-(1R)-3-Ethyl-2,2-dimethylcyclopent-3-ene-1-ethyl Acetate ((−)-**14d**). A soln. of (+)-**14c** (325 g, 1.93 mol) in Ac_2O (800 ml) was heated at 60° during 2 h in the presence of conc. H_3PO_4 (2 ml). The cold soln. was then diluted with H_2O (500 ml). After 1 h, the mixture was neutralized with sat aq. Na_2CO_3 soln. and extracted with Et_2O (3 × 200 ml). The org. phase was successively washed with H_2O and brine, dried (Na_2SO_4), and evaporated: crude oil (406 g). This oil was distilled using a 40-cm helices-packed column: (−)-**14d** (335 g, 83%). Colourless oil. B.p. 90°/3 Torr. $\alpha_D^{20} = -0.65$. IR: 2940, 1730, 1350, 1240. ^{1}H-NMR: 0.78 (*s*, 3 H); 1.00 (*s*, 3 H); 1.07 (*t*, *J* = 7, 3 H); 1.58 (*m*, 1 H); 1.80 (*m*, 2 H); 1.73 (*m*, 3 H); 2.06 (*s*, 3 H); 2.33 (*m*, 1 H); 2.51 (*m*, 2 H); 5.24 (br. *s*, 1 H). ^{13}C-NMR: *Table 4*. MS: 210 (2, M^{+}), 150 (32), 135 (100), 122 (56), 107 (75), 93 (60), 79 (30), 43 (59).

(+)-(1R,3S,5S)-1,2,2-Trimethyl-6,7,8-trioxabicyclo[3.2.1]octane-3-ethyl Acetate ((+)-**15a**). The ozonolysis of (−)-**14b** was effected according to the procedure described for (−)-**14d** → (+)-**16b**. The crude ozonide was used for the next step as a 6:4 mixture of diastereoisomers ($\alpha_D^{20} = +29.6$). A small quantity (5 g) was purified by chromatography (SiO_2, 200 g, toluene/AcOEt 95:5) to give the major (1*R*,3*S*,5*S*)-diastereoisomer first eluted as a 97:3 mixture ($\alpha_D^{20} = +44.2$). The minor (1*S*,3*S*,5*R*)-diastereoisomer was isolated as a 23:77 mixture ($\alpha_D^{20} = +12.3$) in the last fractions (both diastereoisomers have same R_f on TLC). IR: 2990, 1740, 1440, 1370, 1240, 1100, 1020, 900. ^{1}H-NMR: major diastereoisomer: 1.00 (*s*, 3 H); 1.14 (*s*, 3 H); 1.46 (*s*, 3 H); 1.50 (*m*, 1 H); 1.77 (*dt*, *J* = 7, 15, 1 H); 2.05 (*s*, 3 H); 2.10 (*m*, 3 H); 4.08 (*m*, 2 H); 5.73 (br. *s*, 1 H); minor diastereoisomer: 0.94 (*s*, 3 H); 0.96 (*s*, 3 H); 1.30 (*m*, 3 H); 1.48 (*s*, 3 H); 1.80 (*m*, 1 H); 1.90 (*m*, 1 H); 2.06 (*s*, 3 H); 2.15 (*m*, 2 H); 4.06 (*m*, 2 H); 5.71 (br. *s*, 1 H). ^{13}C-NMR: Major diastereoisomer: 17.1 (*Me*−C(1)); 20.9 (*Me*COO); 22.2 (Me_{exo}−C(2)); 26.8 (Me_{endo}−C(2)); 29.8 (CH_2CH_2OAc); 30.5 (C(4)); 38.1 (C(3)); 40.3 (C(2)); 63.8 (CH_2CH_2OAc); 102.4 (C(5)); 112.1 (C(1)); 171.1 (MeCOO); minor diastereoisomer: 16.7 (*Me*−C(1)); 17.7 (Me_{endo}−C(2)); 20.9 (*Me*COO); 21.9 (Me_{exo}−C(2)); 28.9 (CH_2CH_2OAc); 33.5 (C(4)); 33.9 (C(3)); 40.9 (C(2)); 62.8 (CH_2CH_2OAc); 102.0 (C(5)); 112.7 (C(1)); 171.0 (MeCOO). MS: 244 (0, M^{+}), 184 (3), 124 (11), 109 (29), 81 (48), 43 (100).

(+)-(1R,3S,5S)-1-Ethyl-2,2-dimethyl-6,7,8-trioxabicyclo[3.2.1]octane-3-ethyl Acetate ((+)-**15b**). See (−)-**14d** → (+)-**16b**. The crude ozonide (+)-**15b** was used without purification to give (+)-**16b**. A small amount of (+)-**15b** was purified by chromatography (SiO_2, toluene/AcOEt 95:5) to give a 2:1 mixture of the (1*R*,3*S*,5*S*)- and (1*S*,3*S*,5*R*)-diastereoisomers ($\alpha_D^{20} = +35.1$). IR: 2980, 1730, 1360, 1240, 1100. ^{1}H-NMR: major isomer: 0.94 (*t*, *J* = 7, 3 H); 0.96 (*s*, 3 H); 1.12 (*s*, 3 H); 1.28 (*m*, 1 H); 1.48 (*m*, 1 H); 1.7–1.97 (*m*, 4 H); 2.05 (*s*, 3 H); 2.10 (*m*, 1 H); 4.07 (*m*, 2 H); 5.73 (*m*, 1 H); minor isomer: 0.93 (*s*, 3 H); 0.94 (*t*, *J* = 7, 3 H); 0.96 (*s*, 3 H); 1.28 (*m*, 1 H); 1.48 (*m*, 1 H); 1.70–1.97 (*m*, 4 H); 2.06 (*s*, 3 H); 2.10 (*m*, 1 H); 4.07 (*m*, 2 H); 5.72 (*m*, 1 H). ^{13}C-NMR: major isomer: 5.9 (CH_3CH_2); 20.8 (*Me*COO); 21.7 (CH_3CH_2, Me_{exo}−C(2)); 26.5 (Me_{endo}−C(2)); 29.8 (CH_2CH_2OAc); 30.7 (C(4)); 38.5 (C(3)); 40.8 (C(2)); 63.8 (CH_2CH_2OAc); 102.1 (C(5)); 112.6 (C(1)); 171.1 (MeCOO); minor isomer: 6.1 (CH_3CH_2); 17.6 (Me_{endo}−C(2)); 20.9 (*Me*COO); 21.2 (CH_3CH_2); 21.6 (Me_{exo}−C(2)); 28.9 (CH_2CH_2OAc); 33.7 (C(4)); 34.3 (C(3)); 41.2 (C(2)); 62.9 (CH_2CH_2OAc); 101.9 (C(5)); 113.3 (C(1)); 171.0 (MeCOO). MS: 258 (0, M^{+}), 184 (4), 124 (27), 109 (63), 96 (32), 81 (62), 57 (62), 43 (100).

(+)-(1R)-6,6-Dimethyl-5-oxocyclohex-3-ene-1-ethyl Acetate ((+)-**16a**). Obtained from (−)-**14b** in 65% yield after distillation through a 12-cm *Vigreux* column as a colourless oil, according to the procedure used for (−)-**14d** → (+)-**16b**. B.p. 85–89°/0.055 Torr. $\alpha_D^{20} = +56.2$. IR: 2950, 1720, 1660, 1460, 1420, 1380, 1360, 1230. ^{1}H-NMR: 1.00 (*s*, 3 H); 1.18 (*s*, 3 H); 1.53 (*m*, 1 H); 1.93 (*m*, 2 H); 2.06 (*s*, 3 H); 2.17 (*m*, 1 H); 2.52 (*dt*, *J* = 7, 18, 1 H); 4.12 (*m*, 2 H); 5.97 (*d*, *J* = 9, 1 H); 6.84 (*m*, 1 H). ^{13}C-NMR: *Table 5*. MS: 210 (1, M^{+}), 150 (15), 135 (9), 82 (73), 68 (100), 43 (32).

(+)-(1R)-4,6,6-Trimethyl-5-oxocyclohex-3-ene-1-ethyl Acetate ((+)-**16b**). A soln. of (−)-**14d** (304 g, 1.45 mol) in CH_2Cl_2 (800 ml) and MeOH (700 ml) was cooled at −40°, and a flow of O_3 was passed through (18 g/h), until no more starting material was detected. The apparatus was purged with N_2, and Me_2S (285 ml) was added dropwise at −20°. The mixture was stirred overnight at 23° and then concentrated. The crude oil was diluted with cyclohexane (400 ml), and TsOH (13 g, 0.068 mol) was added. The mixture was refluxed during 4 h with continuous separation of H_2O. The cold soln. was washed with H_2O, sat. aq. Na_2CO_3 soln., H_2O, and brine, dried (Na_2SO_4), and evaporated. The crude oil (270 g) was distilled through a 25-cm helices-packed column: pure (+)-**16b** (136 g, 42%). Pale yellow oil. B.p. 88°/0.03 Torr. $\alpha_D^{20} = +65.8$. IR: 2970, 1730, 1660, 1360, 1230, 1030. ^{1}H-NMR: 0.97 (*s*, 3 H); 1.17 (*s*, 3 H); 1.49 (*m*, 1 H); 1.77 (*s*, 3 H); 1.90 (*m*, 2 H); 2.05 (*s*, 3 H); 2.10 (*m*, 1 H); 2.45 (*m*, 1 H); 4.12 (*m*, 2 H); 6.60 (br. *s*, 1 H). ^{13}C-NMR: *Table 5*. MS: 224 (4, M^{+}), 164 (6), 149 (8), 82 (100), 54 (12), 43 (14).

(+)-(1R)-2,2-Dimethyl-3-oxocyclohexane-1-ethyl Acetate ((+)-**17a**). A soln. of (+)-**16a** (33.6 g, 0.16 mol) in EtOH (300 ml) was hydrogenated at r.t./1 atm during 8 h (5 l of H_2) over *Raney*-Ni (1.4 g). The mixture was filtered, evaporated, dried (Na_2SO_4), and distilled: (+)-**17a** (32.2 g, 95%). B.p. 84°/0.05 Torr $\alpha_D^{20} = +64.8$. IR: 2950, 1725, 1700, 1360, 1240. ^{1}H-NMR: 1.04 (*s*, 3 H); 1.11 (*s*, 3 H); 1.45 (*m*, 1 H); 1.56 (*m*, 2 H); 1.62 (*m*, 1 H); 1.86 (*m*,

2 H); 2.00 (*m*, 1 H); 2.05 (*s*, 3 H); 2.31 (*m*, 1 H); 2.56 (*m*, 1 H); 4.04 (*m*, 1 H); 4.17 (*m*, 1 H). ^{13}C-NMR: *Table 5*. MS: 212 (1, M^+), 152 (13), 137 (41), 124 (45), 109 (68), 96 (42), 81 (98), 67 (49), 55 (57), 43 (100).

(+)-(1R,E)-2,2-Dimethyl-3-[(4-tolylsulfonyl)hydrazono]cyclohexane-1-ethyl Acetate ((+)-**17b**). A soln. of (+)-**17a** (50 g, 0.236 mol), tosylhydrazine (44,6 g, 0.24 mol), and conc. H_2SO_4 (2 drops) in MeOH (200 ml) was refluxed for 6 h, then evaporated. The crude oil (101 g) was chromatographed (SiO_2, 500 g, cyclohexane/AcOEt 6:4): crystalline (+)-**17b** (78 g, 87%). M.p. 146–148° (acetone). $[\alpha]_D^{20} = +13.3$ ($c = 2.5$, $CHCl_3$). IR: 3240, 2950, 1725, 1600, 1360, 1325, 1240, 1160. ^{1}H-NMR: 0.90 (*s*, 3 H); 1.10 (*s*, 3 H); 1.27 (*m*, 2 H); 1.34 (*m*, 2 H); 1.77 (*m*, 3 H); 2.43 (*s*, 3 H); 2.45 (*m*, 1 H); 4.02 (*m*, 2 H); 7.31 (*d*, $J = 7$, 2 H); 7.80 (br. *s*, 1 H); 7.85 (*d*, $J = 7$, 2 H). ^{13}C-NMR (systematic numbering): 20.9 (*Me*COO); 21.3 (*Me*–C(2), *cis* to CH_2CH_2OAc); 21.6 (*Me*$C_6H_4SO_2$); 22.9 (C(4)); 23.9, 26.3 (C(5), C(6)); 24.7 (*Me*–C(2)); 28.9 (*C*H_2CH_2OAc); 42.6 C(2)); 43.9 C(1)); 63.3 (CH_2CH_2OAc); 128.3 (C_o); 129.3 (C_m); 135.5 (C_p); 143.7 (C_{ipso}); 166.5 (C(3)); 171.1 (Me*C*OO). MS: 380 (0, M^+), 136 (66), 121 (80), 107 (70), 91 (97), 81 (95), 67 (85), 55 (38), 43 (100).

(+)-(1R)-2,2-Dimethyl-3-methylidenecyclohexane-1-ethyl Acetate ((+)-**17c**). To a soln. of *t*-BuOK (33.6 g, 0.3 mol) and [PPh_3(Me)]I (121.2 g, 0.3 mol) in toluene (500 ml) under reflux was added dropwise a soln. of (+)-**17a** (27 g, 0.127 mol) in toluene (50 ml). After 3 h, the cooled mixture was poured onto ice and extracted with Et_2O (4 × 100 ml). The org. phase was successively washed with sat. aq. NaCl soln. (4 × 100 ml), dried (Na_2SO_4), and evaporated. The crude oil (29.3 g) was purified by chromatography (SiO_2, 580 g, cyclohexane/AcOEt 8:2): (+)-**17c** (19.1 g, 72%). Colourless oil. B.p. 115°/Torr. $\alpha_D^{20} = +58.8$. IR: 2900, 1705, 1600, 1410, 1330, 1200, 1000, 860. ^{1}H-NMR: 0.95 (*s*, 3 H); 1.12 (*s*, 3 H); 1.33 (*m*, 4 H); 1.72 (*m*, 2 H); 1.86 (*m*, 1 H); 2.03 (*s*, 3 H); 2.20 (*m*, 2 H); 4.00 (*m*, 1 H); 4.10 (*m*, 1 H); 4.65 (*s*, 2 H). ^{13}C-NMR: *Table 5*. MS: 210 (0, M^+), 150 (30), 135 (70), 122 (67), 107 (100), 93 (66), 79 (86), 67 (48), 55 (35), 43 (53).

(+)-(1R)-2,2-Dimethyl-3-methylidenecyclohexane-1-ethanol ((+)-**17d**). To a suspension of $LiAlH_4$ (0.4 g, 10.5 mmol) in Et_2O (50 ml) was added dropwise at −10° a soln. of (+)-**17c** (3.6 g, 17.1 mmol) in Et_2O (20 ml). After 1 h at r.t., H_2O (0.4 ml), 15% aq. NaOH soln. (0.4 ml), and H_2O (1.2 ml) were successively added at 0°. The mixture was filtered over *Celite* and evaporated. The crude oil (2.9 g) was purified by bulb-to-bulb distillation: (+)-**17d** (2.77 g, 96%). Colourless oil. B.p. 100°/0.1 Torr. $\alpha_D^{20} = +69$. IR: 3300, 2920, 1630, 1440, 1380, 1160, 1050, 890. ^{1}H-NMR: 0.96 (*s*, 3 H); 1.13 (*s*, 3 H); 1.3 (*m*, 4 H); 1.45 (br. *s*, OH); 1.74 (*m*, 2 H); 1.79 (*m*, 1 H); 2.2 (*m*, 2H); 3.59 (*m*, 1 H); 3.69 (*m*, 1 H); 4.65 (*s*, 2 H). ^{13}C-NMR: *Table 5*. MS: 168 (8, M^+), 153 (11), 135 (41), 123 (61), 107 (100), 93 (45), 79 (99), 67 (94), 55 (70), 41 (68).

(+)-(1R)-2,2-Dimethyl-3-methylidenecyclohexane-1-acetaldehyde ((+)-**18**). Obtained in 99% yield from (+)-**17d** according to the procedure used for (−)-**2k**. B.p. 100°/0.1 Torr. $\alpha_D^{20} = +20.5$. IR: 2940, 1720, 1630, 890. ^{1}H-NMR: 0.96 (*s*, 3 H); 1.14 (*s*, 3 H); 1.40 (*m*, 2 H); 1.70 (*m*, 2 H); 1.94 (*m*, 1 H); 2.15 (*m*, 1 H); 2.22 (*m*, 2 H); 2.57 (*m*, 1 H); 4.70 (*d*, $J = 7$, 2 H); 9.74 (*t*, $J = 2$, 1 H). ^{13}C-NMR: *Table 5*. MS: 166 (4, M^+), 151 (10), 133 (45), 122 (61), 107 (100), 91 (35), 79 (58), 67 (50), 55 (40), 41 (49).

(−)-(1R)-2,2-Dimethylcyclohex-3-ene-1-ethanol ((−)-**19a**). To a soln. of (+)-**17b** (76 g, 0.2 mol) in Et_2O (760 ml) at −5° was added dropwise a soln. of MeLi in Et_2O (580 ml, 1.4M, 0.81 mol). After 15 h at r.t., the mixture was quenched with H_2O (200 ml), extracted twice with Et_2O, washed twice with brine, dried (Na_2SO_4), evaporated, and distilled: (−)-**19a** (24 g, 78%). Colourless oil. B.p. 104–105°/0.011 Torr. $\alpha_D^{20} = -3.32$. IR: 3350, 2940, 1460, 1360, 1050. ^{1}H-NMR: 0.85 (*s*, 3 H); 1.00 (*s*, 3 H); 1.27 (*m*, 1 H); 1.35 (br. *s*, OH); 1.36 (*m*, 1 H); 1.44 (*s*, 1 H); 1.67 (*m*, 1 H); 1.80 (*m*, 1 H); 1.99 (*m*, 2 H); 3.65 (*m*, 1 H); 3.77 (*m*, 1 H); 5.38 (*dt*, $J = 8, 3$, 1 H); 3.54 (*dt*, $J = 8, 3$, 1 H). ^{13}C-NMR: *Table 5*. MS: 154 (2, M^+), 136 (20), 121 (24), 109 (78), 93 (69), 82 (77), 67 (100), 41 (32).

(−)-(1R)-2,2,3-Trimethylcyclohex-3-ene-1-ethyl Acetate ((−)-**19b**). A soln. of (+)-**17c** (7 g, 33.3 mmol) and TsOH (0.2 g, 1.16 mmol) in toluene (50 ml) was refluxed for 2 h. The cold soln. was washed successively with sat. aq. $NaHCO_3$ soln. and brine, and dried (Na_2SO_4). The crude oil was purified by chromatography (SiO_2, 520 g, cyclohexane/AcOEt 9:1) to give (−)-**19b** (4.84 g, 70%). Colourless oil. B.p. 130°/0.1 Torr. $\alpha_D^{20} = -8.9$. IR: 2900, 1700, 1410, 1325, 1200, 1000. ^{1}H-NMR: 0.89 (*s*, 3 H); 1.02 (*s*, 3 H); 1.34 (*m*, 3 H); 1.64 (*s*, 3 H); 1.70 (*m*, 1 H); 1.88 (*m*, 1 H); 1.95 (*m*, 2 H); 2.05 (*s*, 3 H); 4.05 (*m*, 1 H); 4.19 (*m*, 1 H); 5.32 (br. *s*, 1 H). ^{13}C-NMR: *Table 5*. MS: 210 (0, M^+), 150 (23), 135 (60), 121 (19), 107 (100), 96 (32), 93 (37), 81 (53), 69 (18), 55 (14), 43 (27).

(−)-(1R)-*2,2,3-Trimethylcyclohex-3-ene-1-ethanol* ((−)-**19c**). Obtained in 95% yield from (−)-**19b** according to the procedure used for (+)-**17d**. B.p. 100°/0.1 Torr. $\alpha_D^{20} = -12.8$. IR: 3300, 2950, 1440, 1360, 1050. ^{1}H-NMR: 0.89 (*s*, 3 H); 1.03 (*s*, 3 H); 1.34 (*m*, 4 H); 1.50 (*s*, OH); 1.65 (*d*, $J = 2$, 3 H); 1.81 (*dt*, $J = 7, 9$, 1 H); 1.95 (*m*, 2 H); 3.64 (*m*, 1 H); 1.75 (*m*, 1 H); 5.32 (br. *s*, 1 H). ^{13}C-NMR: *Table 5*. MS: 168 (17, M^+), 150 (9), 135 (37), 123 (62), 107 (72), 96 (53), 93 (40), 81 (100), 69 (40), 55 (29), 41 (43).

(−)-(1R)-2,2-Dimethylcyclohex-3-ene-1-acetaldehyde ((−)-**20a**). Obtained in 95% yield according to the procedure used for (−)-**2k**. B.p. 100°/0.01 Torr. $\alpha_D^{20} = -8.7$. IR: 2950, 1720, 1460, 1350, 1025. ^{1}H-NMR: 0.86 (*s*, 3 H); 1.02 (*s*, 3 H); 1.42 (*m*, 1 H); 1.61 (*m*, 1 H); 2.00 (*m*, 3 H); 2.18 (*ddd*, $J = 3, 10, 18$, 1 H); 2.55 (*dd*, $J = 3, 18$,

1 H); 5.38 (*dt*, *J* = 8, 2, 1 H); 5.55 (*dt*, *J* = 8, 3, 1 H); 9.80 (*d*, *J* = 3, 1 H). ^{13}C-NMR: *Table 5*. MS: 152 (2, M^+), 137 (4), 108 (85), 93 (100), 82 (32), 67 (62), 41 (27).

(–)-(1R)(2,2,3-Trimethylcyclohex-3-ene-1-acetaldehyde ((–)-**20b**). Obtained in 92% yield from (–)-**19c** according to the procedure used for (–)-**2k**. B.p. 100°/0.1 Torr. $\alpha_D^{20} = -37.5$. IR: 2960, 2720, 1720, 1440, 1360. ^{1}H-NMR: 0.90 (*s*, 3 H); 1.06 (*s*, 3 H); 1.43 (*m*, 1 H); 1.60 (*m*, 1 H); 1.66 (*d*, *J* = 2, 3 H); 1.98 (*m*, 2 H); 2.03 (*dt*, *J* = 2, 8, 1 H); 2.21 (*dd*, *J* = 2, 8, 15, 1 H); 2.58 (*dd*, *J* = 2, 15, 1 H); 5.35 (br. *s*, 1 H); 9.79 (*dd*, *J* = 1, 3, 1 H). ^{13}C-NMR: *Table 5*. MS: 166 (11, M^+), 133 (25), 121 (39), 107 (100), 96 (26), 91 (31), 81 (62), 69 (20), 55 (18), 41 (32).

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