cis-Disubstituted Cyclopropanes *via* Asymmetric Catalytic Cyclopropenation: Synthesis of Cyclopropyl-dehydroamino Acids and of Dictyopterene C′

by **Hassan Imogaï***, **Gérald Bernardinelli**, **Christian Gränicher**, **Mary Moran**, **Jean-Claude Rossier**, and **Paul Müller***

Department of Organic Chemistry, University of Geneva, 30, Quai Ernest-Ansermet, CH-1211 Geneva 4

The cyclopropenation of diethoxypropyne (**1**) with methyl diazoacetate in the presence of [Rh_2{(2*S*)-mepy}$_4$] (mepy = methyl 5-oxopyrrolidine-2-carboxylate) proceeds with >95% ee. The resulting cyclopropenecarboxylate **2** underwent stereoselective hydrogenation to the *cis*-cyclopropane **3**. Hydrolysis of the acetal function of **3** liberated the formyl cyclopropenecarboxylate **4**, which was transformed by *Wittig* reaction with the phosphonate **5** to afford dehydroamino acid **6** as a mixture of (*Z*)- and (*E*)-isomers in various proportions. The (*Z*)-isomer **6a** was hydrolyzed, and the structure and the absolute configuration of the (*Z*)-dicarboxylic acid **7a** were established by X-ray crystallography. The *cis*-divinylcyclopropane **11** (ee > 95%), in turn, was synthesized from **4** *via Wittig* reaction to afford **8**, which was transformed to the aldehyde **10** and subjected to a second *Wittig* reaction. Thermolysis of **11** afforded (+)-dictyopterene C′ (**12**) in quantitative yield.

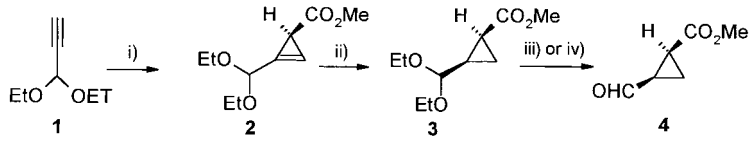
Introduction. – The cyclopropene moiety occurs in numerous natural products [1]. Cyclopropenes are also of considerable interest as synthetic intermediates, allowing access to a variety of diversely functionalized *cis*-cyclopropanes [2] *via* cycloaddition to dienes. Only few methods for asymmetric synthesis of cyclopropenes, and *cis*-cyclopropanes derived thereof, are known [3]. The asymmetric cyclopropanation of olefines with diazoacetates in the presence of chiral transition-metal catalysts may be realized with almost perfect enantioselectivity [4], but this reaction affords either *trans*-cyclopropanecarboxylates exclusively [5][6], or mixtures in which the *trans*-isomer predominates [7]. *cis*-Cyclopropanecarboxylates, in turn, are accessible *via* stereoselective catalytic hydrogenation [8] or diimide reduction [9] of cyclopropene precursors. Alternatively, *cis*-cyclopropanes in optically nearly pure form may be synthesized *via* intramolecular enantioselective cyclopropanation of allylic [10] and homoallylic [11] diazoacetates with chiral Rh^{II} catalysts, or from unsaturated diazo ketones with chiral Cu^{I} complexes [12].

The enantioselective cyclopropenation of terminal acetylenes with diazoacetates or carboxamides catalyzed by chiral Rh^{II} carboxamidates such as [Rh_2{(2*S*)-mepy}$_4$] [13], has been developed in collaboration with the group of *Doyle* [14]. The reaction affords cyclopropenes with varying enantioselectivities, depending upon the substituents of the diazo compound, the acetylene, and upon the ligands of the catalyst. If the acetylene carries alkoxy or protected amino groups [15] adjacent to the C≡C bond, the enantioselectivity may reach synthetically useful levels (> 95%). Diimide reduction to *cis*-cyclopropanecarboxylates occurs at less hindered face and affords *cis*-cyclopropanecarboxylates exclusively. The objective of the present study was to optimize this

sequence and to apply it to the synthesis of compounds of current chemical or biological interest.

Results and Discussion. – *Cyclopropenation of 1,1-Diethoxypropyne.* The previously reported cyclopropenation of diethoxypropyne (**1**) with methyl diazoacetate (MDA) under catalysis with [Rh_2\{(2*S*)-mepy\}$_4$] (mepy = methyl 5-oxopyrrolidine-2-carboxylate) to the (1*S*)-cyclopropenecarboxylate **2**, and the subsequent diimide reduction of **2** to the *cis*-(1*S*,2*R*)-cyclopropane (**3**) [14] was optimized (*Scheme 1*). The procedure of choice for the cyclopropenation involves slow (syringe pump, 30 h) addition of 1 equiv. of MDA to 2 equiv. of **1** and 2% of catalyst (with respect to MDA) in CH_2Cl_2 at room temperature. The cyclopropene **2** was obtained in 85% yield on a 40-mmol scale, and was purified by column chromatography. The experiment was repeated more than 20 times. The ee of **2**, as determined by NMR of the Me group of the ester ([Eu(hfc)$_3$]), varied in the range of 88–95%. These variations are probably due to different qualities of the catalyst.

Scheme 1



i) [Rh_2\{(2*S*)-mepy\}$_4$], 0.5 equiv. N_2CHCO_2Me, CH_2Cl_2, 20°; 85%. ii) Pd/C, H_2, MeOH, 20°; 92%. iii) $HClO_4$, THF; 70%. iv) 2N HCl, THF, 20°; 85%.

For the reduction of **2** to the *cis*-cyclopropane **3**, catalytic hydrogenation was found superior to diimide reduction. Overreduction of **3** could be avoided by careful control of the reaction conditions (Pd/C, in MeOH, 1.0 equiv. of H_2), and **3** was isolated in 92% yield. Mild acid hydrolysis of the acetal function of **3** afforded the formyl derivative **4** (85%).

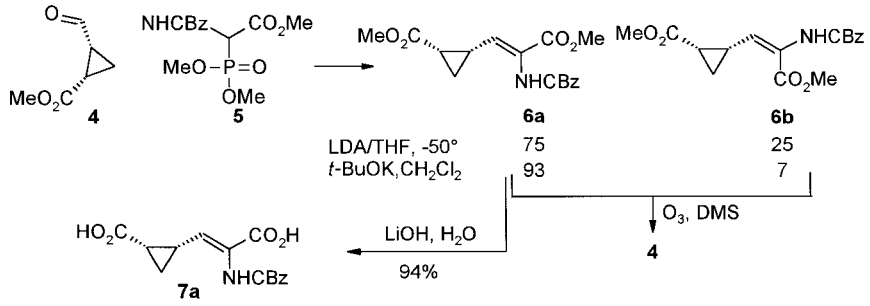
The enantiomer of **4**, *cis*-2-formylcyclopropanecarboxylate, having (1*R*,2*S*)-configuration, has previously been synthesized in optically pure form in eleven steps starting from ribonolactone [16]. The compound is conveniently functionalized for the introduction of one or two vinyl groups *via Wittig* reaction.

Synthesis of Methyl (E)*- or* (Z)*-2-[(Benzyloxycarbonyl)amino]-3-[(1*S,2S*)-2-(methoxycarbonyl)cyclopropyl]prop-2-enoate* (**6a** or **6b**). Cyclopropaneamino acids are compounds of current interest owing or their biological activity [17] and to their use as isosters in peptide analogs [18]. Typical representatives of this class of compounds are the coronamic-acid family [19][20] and cilastatin, a well-known enzyme inhibitor, where the cyclopropane ring is attached to a conjugated C=C bond [21]. Several groups have concentrated their interest on dehydroamino acids with a cyclopropane ring, owing to their potential interference in biological processes [16][22]. Recently *Hanafi* and *Ortuño* [16b] reported the *Wittig* reaction of optically pure methyl *cis*-2-formylcyclopropanecarboxylate (**4**), with methyl 2-[(benzyloxycarbonyl)amino]-2-(dimethoxyphosphonyl)acetate (**5**) [23] in the presence of lithium diisopropylamide (LDA). The cyclopropyl-dehydroamino acid methyl ester **6a** was obtained as a single

stereoisomer [16]. The (*Z*)-configuration of the C=C bond was established by NOE experiments.

In our hands, the reaction of **4** with **5** under the conditions used by *Hanafi* and *Ortuño* (with LDA as base) afforded two stereoisomers **6a** and **6b** in a 3:1 ratio (by NMR) (*Scheme 2*). This ratio changed to 93:7 when *t*-BuOK/CH_2Cl_2 [24] was used as base for the *Wittig* reaction[1]). The isomers were separated by column chromatography. Separate ozonolysis of both stereoisomers regenerated **4** with $[\alpha]_D^{20} = +168$ ($c = 0.75$, $CHCl_3$), identical to that of authentic **4**, thereby indicating that no *cis*/*trans*-isomerization at the cyclopropane ring had occurred during the condensation with **5**.

Scheme 2



CBz = Benzyloxycarbonyl, DMS = dimethyl sulfide

The (*Z*)-configuration was tentatively assigned to the major isomer **6a**, in conformity to that proposed by *Hanafi* and *Ortuño* [16]. However, discrepancies with the data in the literature made this assignment questionable. The (*Z*)-isomer described by *Hanafi* and *Ortuño* is the enantiomer of **6a** with $[\alpha]_D^{20} = -73$ (for 1*R*,2*R*)-configuration, but our own measurements for **6a** yielded $[\alpha]_D^{20} = +149$ ($c = 1.5$, $CHCl_3$), and $[\alpha]_D^{20} = +64$ ($c = 1.5$, $CHCl_3$) for the (*E*)-isomer **6b**. In addition, we were unable to observe the NOEs reported between the proton H_b–C(3′) of the CH_2 group of the cyclopropane and the olefinic proton (H–C(3)), and that between H–C(1′) and H–N(2). In the case of the (*E*)-isomer, the signals of H–N(2) and H–C(3) coïncided, and the NOE signals were not conclusive because of the possibility of simultaneous occurrence of both scalar and spatial coupling.

The configurational assignment was finally accomplished on the grounds of the $^1H,^{13}C$ coupling constants between the olefinic proton H–C(3) and the *C*(1)=O, measured by gated experiments [25] on a *Bruker* 400-MHz NMR spectrometer (*Fig. 1*). The C-atom C(1) of the (*Z*)-isomer **6a** resonates at 164.7 ppm. $^1H,^{13}C$ Couplings are observed with the Me group (^3J(C(1), Me) = 4.2 Hz) and with the olefinic proton ($^3J(H–C(3), C(1)) = 4–5$ Hz). In the case of the (*E*)-isomer **6b**, C(1) resonates at 164.2 ppm, and the corresponding *J* values are 4.2 and 12.0 Hz, respectively. Simulation of the spectra, taking into consideration the half-width of the peaks, resulted in calculated values of $^3J(H–C(3),C(1)) = 4.8$ Hz for **6a** and 12 Hz

[1]) Equilibration of the mixture by weak acid afforded a 1:1 ratio of **6a** and **6b**.

for **6b**. Typical values of 5.5 Hz have been reported for analogous (*Z*)-isomers, and of 12.5 Hz for (*E*)-isomers [22][25].

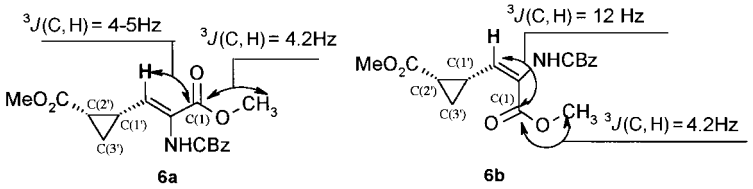


Fig. 1. *^{3}J(C(1), H) Values for* **6a** *and* **6b**

Both isomers of **6** occurred as amorphous solids, which were unsuitable for X-ray crystal-structure determination. The major isomer (*Z*)-**6a** was subjected to mild hydrolysis with LiOH in dioxane/H_2O (*Scheme 2*). The resulting (*Z*)-dicarboxylic acid **7a** recrystallized in $CHCl_3$ as an inclusion compound with the solvent. Although the data of the crystallographic resolution showed large uncertainties in the final parameters and high *R* values (*ca.* 10.6%), the (*Z*)-configuration of the C=C bond and the absolute configuration (1*S*,2*S*) could be unambiguously established (absolute structure parameter [26] $x = 0.04(9)$). This confirms independently the (1*S*)-configuration of the cyclopropene **2** which had been established previously by chemical correlation [14]. A second recrystallization of **7a** from AcOEt afforded crystals of suitable quality for structure determination (see *Exper. Part* and *Fig. 2*).

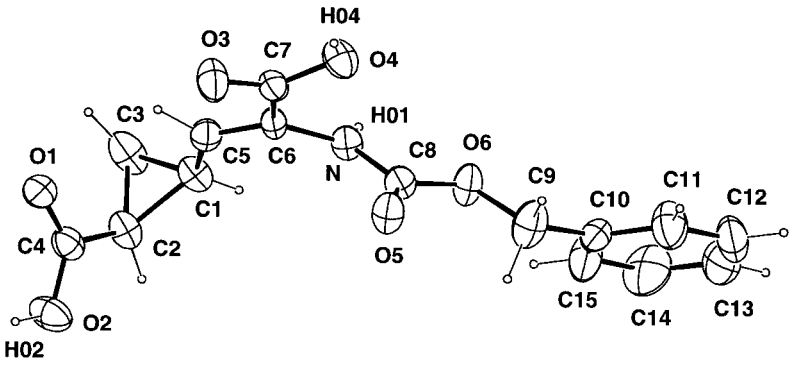


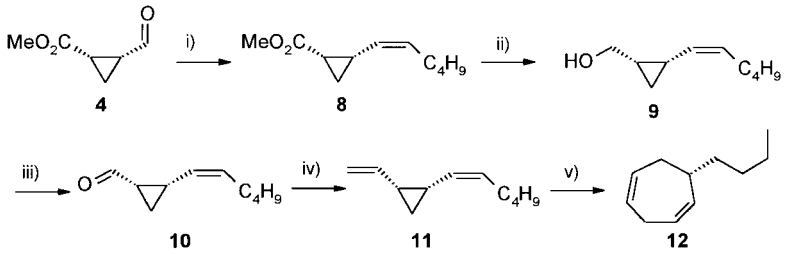
Fig. 2. *Perspective view of the crystal structure of* **7a** *with arbitrary atomic numbering.* Ellipsoids are represented with 40% probability level.

Synthesis of Dictyopterene C′. Dictyopterenes are unsaturated hydrocarbon pheromones isolated from the essential oil of a seaweed (*dictyopteris*) [27]. They are believed to originate from rearrangement of poly-unsaturated alcohols [28]. Dictyopterenes occur as *cis*- or *trans*-divinylcyclopropanes, or cycloheptadienes, the latter resulting from concerted *Cope* rearrangement of *cis*-divinylcyclopropanes [29]. Non-stereospecific dictyopterene syntheses date back to 1969 [30][31], and the first stereospecific version appeared in 1980 [32]. Subsequently, optically active dictyopterenes have been synthesized by several approaches such as asymmetric synthesis using

chiral auxillaries [33], metal-catalyzed chirality transfer [34], enzymatic resolution of *meso*-compounds [35], or classical resolution of racemates [36].

The availability of the *cis*-cyclopropane **4** opens a simple access to dictyopterenes by sequential introduction of appropriate vinyl groups *via Wittig* reaction, as exemplified for dictyopterene C′. The formyl ester **4** was transformed to the (*Z*)-olefin **8** [35] in 70% yield. The ee value of **8** was >95% (by GC), indicating absence of racemization during the olefination. Direct DIBAL reduction of **8** (1.2 equiv, −50°) to the aldehyde **10** was attempted in different solvents (hexane, toluene, CH_2Cl_2) with unsatisfactory results and resulted in a mixture of the desired aldehyde **10**, alcohol **9**, and unreacted ester **8**. The ester was, therefore, reduced to **9**, and subsequent oxidation with pyridinium chlorochromate (PCC) afforded **10** ($[\alpha]_D^{20} = +233$ ($c = 0.60$, CH_2Cl_2); [31]: $[\alpha]_D^{22} = -244.8$ ($c = 0.62$, CH_2Cl_2) for (−)-isomer). The *cis*-isomer of (+)-dictyopterene C (**11**) ($[\alpha]_D^{20} = +119$ ($c = 1.60$, CH_2Cl_2); [34]: $[\alpha]_D^{22} = -124.8$ ($c = 2.35$, CCl_4) for (−)-isomer) was obtained upon reaction of **10** with $CH_2{=}P(Ph)_3$. The compound **11** rearranged quantitatively at 75° in CCl_4 to (+)-dictyopterene C′ (**12**) with $[\alpha]_D^{22} = +15.4$ ($c = 0.30$, $CHCl_3$) ([35]: $[\alpha]_D^{20} = +17.1$ ($c = 0.32$, $CHCl_3$)).

Scheme 3



i) $Ph_3PC_5H_{11}Br$, NaHMDS (sodium hexamethyldisilazane), −78°, HMPA; 70%. ii) DIBAL-H, −50°; 90%. iii) PCC, NaOAc, CH_2Cl_2; 87%. iv) Ph_3PCH_3Br, NaHMDS, Et_2O, −50°; 98%. v) Δ, CCl_4; 100%.

In an alternative approach to **12**, a sequence involving first, after protection of the CHO group as an acetal, transformation of the ester group of **3** to an aldehyde and *Wittig* reaction of the latter before hydrolysis of the acetal, was also explored. However, this sequence suffered from low yields and product decomposition, presumably owing to the lability of the acetal group.

The authors are indebted to Dr. *Y. Jeannerat* for the gated NMR experiments, to Mrs. *A. Pinto* and *J.-P. Saulnier* for the routine NMR spectra, and to Ms. *G. Klink* for the mass spectra. Financial support of this work by the *Swiss National Science* foundation (grant No. 20-45255.95 and 20-48156.96) is gratefully acknowledged.

Experimental Part

General. See [37]. The [Rh_2\{(2*S*)-mepy\}$_4$] catalyst (mepy = methyl 5-oxopyrrolidine-2-carboxylate) was prepared as described by *Doyle et al*. [13]. The catalyst was dried before use by heating with an air-gun to 200° in the reaction flask under reduced pressure (color change from violet to blue).

Synthesis of Methyl cis-*(1S,2R)-2-Formylcyclopropane-1-carboxylate* (**4**). *Methyl (1S)-2-(Diethoxymethyl)-cycloprop-2-ene-1-carboxylate* (**2**). To a soln. of [Rh_2\{(2*S*)-mepy\}$_4$] (366 mg, 0.40 mmol) and **1** (5.12 g, 40 mmol) in CH_2Cl_2 (60 ml) at r.t., methyl diazoacetate (2.0 g, 20 mmol) in CH_2Cl_2 (60 ml) was added within 30 h by syringe pump. After the addition, the mixture was concentrated under reduced pressure (40 Torr). The crude

product was purified by CC (silica gel (100 g), pretreated with 1% of Et_3N) with hexane/AcOEt acetate 90:10: **2** (3.34 g, 85%). Transparent liquid. $[\alpha]_D^{20} = +52$ ($c = 0.50$, $CHCl_3$) for >95% ee (by NMR with [Eu(hfc)]). IR (film): 2984*m*, 1726*s*, 1431*w*, 1202*w*, 1051*m*. ^{1}H-NMR (400 MHz, $CDCl_3$): 1.18 (*t*, *J* = 7.1, 3 H); 1.19 (*t*, *J* = 7.1, 3 H); 2.33 (*d*, *J* = 1.4, 1 H); 3.54–3.71 (*m*, 4 H); 3.65 (*s*, 3 H); 5.48 (*d*, *J* = 1.8, 1 H); 6.76–6.78 (*m*, 1 H). ^{13}C-NMR ($CDCl_3$): 15.0 (*q*); 15.2 (*q*); 20.5 (*q*); 51.6 (*q*); 61.2 (*t*); 61.5 (*t*); 96.5 (*d*); 100.2 (*d*); 112.6 (*s*); 175.3 (*s*). MS: 200 (M^+ absent), 171(7), 169(1), 155(17), 127(68), 112(61), 103(62), 75(55), 59(33), 47(100).

Methyl cis-*(1*S*,2*R*)-2-(Diethoxymethyl)cyclopropane-1-carboxylate* (**3**). A suspension of Pd/C catalyst (10%, 350 mg) in degassed MeOH (100 ml) was purged several times with H_2. Cyclopropene **2** (3.50 g, 17.5 mmol) in MeOH (20 ml) was added by means of a syringe through a septum. The mixture was stirred magnetically under H_2 until absorption of 1 equiv. (*ca.* 15 min). The mixture was degassed under reduced pressure, then flushed with N_2, and concentrated under reduced pressure (40 Torr). The crude product was purified by CC (carbonated silica gel; hexane/AcOEt 4:1) to afford **3** (3.20 g, 92%). Colorless oil. $[\alpha]_D^{20} = +39$ ($c = 0.80$, $CDCl_3$). IR (film): 2964*w*, 1725*s*, 1436*w*, 1381*m*, 1196–1054*m*. ^{1}H-NMR (400 MHz, $CDCl_3$): 1.09 (*t*, *J* = 7.0, 3 H); 1.17 (*t*, *J* = 7.0, 3 H); 1.05–1.23 (*m*, 2 H); 1.53–1.61 (*m*, 1 H); 1.74–1.80 (*m*, 1 H); 3.52–3.68 (*m*, 4 H); 3.68 (*s*, 3 H); 4.47 (*d*, *J* = 8.0, 1 H). ^{13}C-NMR ($CDCl_3$): 11.6 (*t*); 15.2 (*q*); 15.4 (*q*); 16.9 (*d*); 23.8 (*d*); 51.9 (*q*); 61.4 (*t*); 61.8 (*t*); 101.6 (*d*); 172.8 (*s*). MS: 202 (M^+ absent), 157(60), 143(49), 115(66), 97(100), 75(36), 59(39), 55(38).

Methyl cis-*(1*S*,2*R*)-2-Formylcyclopropane-1-carboxylate* (**4**). To **3** (3.25 g, 16.3 mmol) in THF (65 ml) at 0°, 2N HCl (24.4 ml, 48 mmol) was added. The mixture was stirred during 2 h at 20°, then the solvent was evaporated (40 Torr). The crude residue was dissolved in Et_2O (50 ml), and washed with sat. $NaHCO_3$ (10 ml). After drying ($MgSO_4$) and evaporation of the solvent, the crude product was rapidly purified by CC (carbonated silica gel; hexane/AcOEt 70:30): **4** (1.77 g, 85%). Colorless oil. $[\alpha]_D^{20} = +166$ ($c = 0.70$, $CHCl_3$) for >95% (by NMR, [Eu(hfc)$_3$]). IR ($CHCl_3$): 1730*s*, 1709*s*, 1441*w*, 1387*m*, 1202*m*. ^{1}H-NMR (400 MHz, $CDCl_3$): 1.55 (*ddd*, *J* = 8.4, 8.4, 5.3, 1 H); 1.93 (*ddd*, *J* = 6.6, 6.6, 5.3, 1 H); 2.06 (*dddd*, *J* = 8.4, 8.4, 6.6, 6.4, 1 H); 2.25 (*ddd*, *J* = 8.4, 8.4, 6.6, 1 H); 3.74 (*s*, 3 H); 9.34 (*d*, *J* = 6.6, 1 H). ^{13}C-NMR ($CDCl_3$): 13.1 (*t*); 22.3 (*d*); 30.0 (*d*); 52.3 (*q*); 172.7 (*s*); 199.6 (*s*). MS: 145 (0.4, $[M + H_2O]^+$), 131(5), 128 (0.4, M^+), 115(15), 100(64), 97(61), 87(33), 68(62), 68(53), 59(100), 55(76). HR-MS: 128.0475 ($C_8H_8O_3^+$; calc. 128.0474).

*Methyl (*Z*)- and (*E*)-2-[(Benzyloxycarbonyl)amino]-3-[(1*S*,2*S*)-2-(methoxycarbonyl)cyclopropyl]prop-2-enoate* (**6a** and **6b**). To a soln. of $(i\text{-}Pr)_2NH$ (1.53 ml, 13 mmol) in THF (60 ml) at −78°, a soln. of BuLi (8.1 ml, 1.6M in hexane, 13 mmol) was added dropwise. The mixture was heated to −10° during 10 min, whereupon a soln. of phosphonate **5** (4.5 g, 15 mmol) in THF (30 ml) was added dropwise. After 30 min of stirring, the suspension was cooled to −78°, and **4** (1.28 g, 10.0 mmol) in THF was added within 10 min. The mixture was allowed to warm to r.t. overnight, and then hydrolyzed with H_2O (100 ml). The layers were separated, and the aqueous layer was extracted with CH_2Cl_2 (3 × 100 ml). Crude **6** was isolated after drying ($MgSO_4$) and evaporation of the org. phase, and was purified by CC (silica gel; AcOEt/petroleum ether 1:2) to yield **6a** (1.80 g), m.p. 149°, and **6b** (530 mg), m.p. 58°; overall yield 70%.

When the reaction was carried out with *t*-BuOK in CH_2Cl_2 at −78°, **6a** and **6b** were formed in a ratio of 93:7 in an overall yield of 71%.

Data of **6a**: $[\alpha]_D^{20} = +149$ ($c = 1.5$, $CHCl_3$). IR ($CHCl_3$): 1724*s* (large) 1502*s*, 1439*s*. ^{1}H-NMR (400 MHz, $CDCl_3$): 1.38–1.42 (*m*, 2 H); 2.09–2.22 (*m*, 2 H); 3.69 (*s*, 3 H); 3.73 (*s*, 3 H); 5.14 (*s*, 2 H); 6.43 (*s*, 1 H); 6.72 (*d*, *J* = 9.8, 1 H); 7.34–7.36 (*m*, 5 H). ^{13}C-NMR ($CDCl_3$): 15.7 (*t*); 20.4 (*d*); 21.9 (*d*); 51.9 (*q*); 52.3 (*q*); 67.3 (*t*); 126.3 (*s*); 128.0 (*d*); 128.1 (*d*); 128.5 (*d*); 134.7 (*d*); 135.9 (*s*); 154.2 (*s*); 164.7 (*s*); 172.0 (*s*). MS: 334 (0.8, $M + 1]^+$), 333 (0.3, M^+), 242(11), 230(22), 156(10), 107(11), 92(24), 91(100), 80(11), 79(14), 65(18), 53(13).

Data of **6b**: $[\alpha]_D^{20} = +64$ ($c = 1.5$, $CHCl_3$). IR ($CHCl_3$): 1725*s*, 1518*s*, 1441*s*. ^{1}H-NMR (400 MHz, 55°, 6-s time lag, $CDCl_3$): 1.34–1.41 (*m*, 2 H); 2.09 (*ddd*, *J* = 8.3, 8.3, 5.9, 1 H); 3.01 (*dddd*, *J* = 8.3, 8.3, 6.1, 10.3, 1 H); 3.70 (*s*, 3 H); 3.88 (*s*, 3 H); 5.13 (*s*, 2 H); 6.69 (*s*, 1 H); 6.74 (*d*, *J* = 10.3, 1 H); 7.26–7.36 (*m*, 5 H). ^{13}C-NMR (55°, 6-s time lag, $CDCl_3$): 16.1 (*t*); 20.0 (*d*); 22.2 (*d*); 51.7 (*q*); 52.1 (*q*); 67.0 (*t*); 125.8 (*s*); 128.1 (*d*); 128.2 (*s*); 128.5 (*d*); 129.6 (*d*); 136.3 (*s*); 153.7 (*s*); 164.2 (*s*); 171.9 (*s*). MS: 333 (1.6, M^+), 274 (43), 242(28), 230(53), 156(25); 107(25), 92(2), 91(100), 65(50). HR-MS: 333.1243 ($C_{17}H_{19}NO_6^+$; calc. 333.1213).

Ozonolysis of **6a** *or* **6b**. A stream of O_3 was introduced to **6a** or **6b** (333 mg, 1.0 mmol) in CH_2Cl_2 (20 ml), until a blue color persisted in soln. for 5–10 min. The excess of O_3 was removed by blowing a stream of Ar through the soln. Me_2S (5.0 ml) was added at −78°, and the mixture was allowed to reach r.t. overnight. The solvent was evaporated under reduced pressure (140 Torr), and the residue was purified by CC (silica gel; hexane/AcOEt 7:3). The aldehyde **4** (90 mg, 70%) was isolated as colorless liquid with spectral and physical data identical to those of authentic **4**.

Hydrolysis of **6a**. *(Z)-2-[(Benzyloxycarbonyl)amino]-3-[(1S,2S)-2-carboxycyclopropyl]prop-2-enoic Acid* (**7a**). To **6a** (40 mg, 1.12 mmol) in dioxan (1.0 ml) and H_2O (0.75 ml), $LiOH \cdot H_2O$ (15 mg, 0.36 mmol) was added. The mixture was stirred for 48 h, and the solvent was evaporated. The aq. layer was extracted with Et_2O (2 ml), then acidified to pH 1 with 1N HCl, and extracted with AcOEt (5 × 6 ml). After drying (Na_2SO_4) and evaporation **7a** was isolated as colorless oil, which was precipitated with $CHCl_3$ and filtered. Yield 34 mg (94%). Amorphous solid. M.p. 162°. $[\alpha]_D^{20} = +137$ ($c = 1.35$, acetone).

Crystal Structures of **7a**. All crystals obtained from **7a** lead to inclusion compounds with solvent molecules and a rapid decomposition of the crystals out of the mother liquors occurred.

7a · *$CHCl_3$*. Crystallization of **7a** from $CHCl_3$ soln. gives crystals with two **7a** and 2 $CHCl_3$ molecules by asymmetric unit. The crystal quality and the large displacement parameters of one $CHCl_3$ lead to large uncertainties on the final geometrical parameters and high R values (*ca.* 10.6%). Nevertheless, the absolute configuration of **7a** could be unambiguously established as (1*S*,2*S*) (refinement of the *Flack* parameter [26] $x = 0.04(9)$). The conformation of both molecules of the asymmetric unit essentially differs by the relative orientation of their Ph substituent (*ca.* 20°).

7a · *0.5 AcOEt*. Crystallization of **7a** from AcOEt soln. gives crystals showing a destructive phase transition at 180 K and including solvent molecules located in channels parallel to the [100] direction. The AcOEt molecules are disordered, and four atomic sites have been refined with population parameters of 0.5. The absolute configuration of **7a** has been fixed as observed in the **7a** · $CHCl_3$ crystal structure. H-Atoms have been observed and refined with isotropic displacement parameters fixed to 0.05 Å^2. All potential donors and acceptors are involved in a tridimensional network of H-bonds (see *Table 1*).

Table 1. *Crystal Data, Intensity Measurement, and Structure Refinement for* **7a** · *$CHCl_3$ and* **7a** · *0.5 AcOEt*

	7a · $CHCl_3$ [a])	**7a** · 0.5 AcOEt
Formula	$(C_{15}H_{15}NO_5)(CHCl_3)$	$(C_{15}H_{15}NO_5)(C_4H_8NO_2)_{0.5}$
Mol. wt.	424.7	349.3
Crystal color	Colorless	Colorless
Crystal size [mm]	0.22 × 0.25 × 0.30	0.096 × 0.15 × 0.44
Crystal system	Monoclinic	Orthorhombic
Space group	$P2_1$	$P2_12_12_1$
a [Å]	10.006(1)	5.0830(4)
b [Å]	13.027(1)	12.852(1)
c [Å]	14.791(1)	25.326(2)
β [°]	101.343(6)	90.0
V [Å^3]	1890.3(3)	1654.5(2)
Z	4	4
Temp. [K]	200	200
$F(000)$	872	736
D_c [g · cm^{-3}]	1.49	1.40
$\mu(CuK_\alpha)$ [mm^{-1}]	4.689	0.811
A*min, max	2.082, 7.287	1.080, 1.185
$((\sin\theta)/\lambda)_{max}$ [Å^{-1}]	0.53	0.53
Temp. [K]	200	200
No. measured refl.	4899	2463
No. observed refl.	3713	1729
Criterion for observed	$\lvert F_o\rvert > 4\sigma(F_o)$	$\lvert F_o\rvert > 4\sigma(F_o)$
Refinement (on F)	Full-matrix	Full-matrix
No. parameters	471	281
Absolute structure parameter χ	0.04(9)	–
Weighting scheme	$w = 1/[\sigma^2(F_o) + 0.001(F_o^2)]$	$w = 1/[\sigma^2(F_o) + 0.0003(F_o^2)]$
Max. and min. $\Delta\rho$ [e · Å^{-3}]	1.21, −0.97	0.18, −0.21
S	3.99(8)	1.52(4)
R, wR	0.109, 0.106	0.042, 0.043

[a]) The crystal data for this compound have not been deposited (see *Exper. Part*).

Table 2. *Selected Bond Lengths* [Å], *Bond Angles, and Torsional Angles* [°] *for* **7a**·*0.5 AcOEt*[a])

O(1)–C(4)	1.245(6)	O(2)–C(4)	1.286(6)
O(3)–C(7)	1.231(6)	O(4)–C(7)	1.312(6)
O(5)–C(8)	1.220(6)	O(6)–C(8)	1.342(6)
O(6)–C(9)	1.465(7)	N–C(6)	1.421(6)
N–C(8)	1.354(7)	C(1)–C(2)	1.551(7)
C(1)–C(3)	1.483(8)	C(1)–C(5)	1.469(7)
C(2)–C(3)	1.502(8)	C(2)–C(4)	1.466(8)
C(5)–C(6)	1.334(7)	C(6)–C(7)	1.474(7)
C(8)–O(6)–C(9)	114.4(4)	C(6)–N–C(8)	121.3(4)
C(2)–C(1)–C(3)	59.3(4)	C(2)–C(1)–C(5)	120.3(5)
C(3)–C(1)–C(5)	119.7(5)	C(1)–C(2)–C(3)	58.1(4)
C(1)–C(2)–C(4)	121.0(5)	C(3)–C(2)–C(4)	119.1(5)
C(1)–C(3)–C(2)	62.6(4)	C(1)–C(5)–C(6)	126.3(4)
N–C(6)–C(5)	123.1(4)	N–C(6)–C(7)	117.8(4)
C(5)–C(6)–C(7)	119.1(4)	O(6)–C(9)–C(10)	108.5(5)
C(3)–C(2)–C(4)–O(1)	–24.7(8)	C(5)–C(1)–C(2)–C(4)	1.6(8)
C(5)–C(1)–C(3)–C(2)	–109.7(5)	C(2)–C(1)–C(5)–C(6)	139.3(5)
C(3)–C(1)–C(5)–C(6)	–151.0(5)	C(4)–C(2)–C(3)–C(1)	110.4(5)
C(1)–C(5)–C(6)–C(7)	–177.2(5)	C(1)–C(5)–C(6)–N	4.2(8)
C(5)–C(6)–C(7)–O(3)	15.2(7)	C(8)–N–C(6)–C(5)	–131.5(5)
C(6)–N–C(8)–O(5)	10.1(8)	C(6)–N–C(8)–O(6)	–170.9(4)
C(9)–O(6)–C(8)–N	178.0(4)	C(8)–O(6)–C(9)–C(10)	169.6(4)
O(6)–C(9)–C(10)–C(11)	140.0(6)		

H-Bonds

N···O(5)[b])	2.910(6) Å	H(01)···O(5)[b])	2.13(6) Å	N–H(01)···O(5)[b])	156(5)°
O(2)···O(3)[c])	2.600(5) Å	H(02)···O(3)[c])	1.66(5) Å	O(2)–H(02)···O(3)[c])	177(4)°
O(4)···O(1)[d])	2.641(5) Å	H(04)···O(1)[d])	1.78(5) Å	O(4)–H(04)···O(1)[d])	171(4)°

[a]) See *Fig. 2* for the atom numbering. Equivalent positions: [b]) $x+1, y, z$; [c]) $-x, y+1/2, 3/2-z$; [d]) $-x, y-1/2, 3/2-z$.

Both structures were solved by direct methods using MULTAN 87 [38], all other calculations used XTAL [39] system and ORTEP [40] programs. Data were corrected for *Lorentz* and polarization effects and for absorption by analytical integration from the crystal shape [41]. A summary of crystallographic data and selected geometrical parameters are reported in *Tables 1* and *2*, resp.

Crystallographic data (excluding structure factors) for **7a**·0.5 AcOEt have been deposited with the *Cambridge Crystallographic Data Center* as deposition No. CCDC-101872. Copies of the data can be obtained free of charge on application to the CCDC, 12 Union Road, Cambridge CB2 1EZ, UK (fax: +44 (1223) 336-033; e-mail: deposit@ccdc.cam.ac.uk).

Synthesis of Dictyopterene C′ (**12**). *Methyl* cis-*(1S,2S)-2-[(Z)-hex-1-enyl]cyclopropane-1-carboxylate* (**8**). To a suspension of $Ph_3PC_5H_{11}Br$ (9.26 g, 20 mmol) in THF was added, at −30° NaHMDS (20 ml, 1M in hexane, 20 mmol) with stirring. The mixture was stirred at 15° during 20 min. HMPA (7.4 ml, 80 mmol) was added at −50°. After stirring for 10 min, **4** (1.28 g, 10 mmol) in THF (8.0 ml) was added to the soln. dropwise at −78°. The reaction was complete after 20 min. The mixture was allowed to warm up to 10°, and was then decomposed with H_2O (100 ml). The aq. layer was extracted with pentane/Et_2O 4:1 (4 × 100 ml). The org. phase was washed several time with sat. NaCl, dried ($MgSO_4$), filtered, and concentrated. The crude product was purified by CC (silica gel; hexane/AcOEt 93:3): **8** (1.28 g, 70%). Colorless liquid. $[\alpha]_D^{22} = +247$ ($c = 1.0$, $CHCl_3$). IR ($CHCl_3$): 2957*w*, 1736*s*, 1433*s*, 1372*m*, 1207*s*, 1180*m*. ^{1}H-NMR (200 MHz, $CDCl_3$): 0.90 (*t*, *J* = 6.7, 3 H); 0.88–0.92 (*m*, 3 H); 1.18–1.43 (*m*, 6 H); 1.86–1.98 (*m*, 1 H); 2.05–2.22 (*m*, 3 H); 3.67 (*s*, 1 H); 5.32 (*ddt*, *J* = 10.2, 8.8, 1.2, 1 H); 5.49 (*ddt*, *J* = 10.9, 7.3, 0.9, 1 H). ^{13}C-NMR: 13.9 (*q*); 14.6 (*t*); 19.3 (*d*); 20.8 (*d*); 22.3 (*t*); 31.7 (*t*); 51.0 (*q*); 126.0 (*d*); 132.4 (*d*); 172.6 (*s*); MS: 182 (36, M^+), 153(4), 139(24), 111(50), 93(33), 79(100), 55(42). HR-MS: 182.1299 ($C_{11}H_{18}O_2^+$; calc. 182.1307).

cis-*(1S,2S)-2-[(Z)-Hex-1-enyl]cyclopropane-1-methanol* (**9**). To **8** (728 mg, 4.0 mmol) in Et_2O (20 ml) at $-50°$, DIBAL-H (8.8 ml, 1M in hexane, 8.8 mmol) was added with stirring. After 2 h, the mixture was decomposed with NH_4Cl/HCl (12 ml, 1.5M). The org. layer was extracted with Et_2O (3×15 ml). After drying ($MgSO_4$) and evaporation, the crude product was purified by CC (silica gel; hexane/AcOEt 9 : 1): **10** (554 mg, 90%). Colorless liquid. $[\alpha]_D^{20} = +94$ ($c = 1.8$, $CHCl_3$), ([35]: $[\alpha]_D^{20} = -94.9$ ($c = 1.7$, $CHCl_3$) for (−)-isomer; [36a]: $[\alpha]_D^{25} = +80.0$ ($c = 2.2$, CH_2Cl_2), $[\alpha]_D^{25} = -81.2$ ($c = 2.6$, CH_2Cl_2)). IR (KBr): 3334*s* (large), 3070–3010*m*, 1665*s*, 1645*w*, 1033*s*. ^{1}H-NMR (200 MHz, $CDCl_3$): 0.33–0.39 (*m*, 1 H); 0.93 (*t*, $J = 7.2$, 3 H); 0.95–1.04 (*m*, 1 H); 1.14–1.31 (*m*, 5 H); 1.45–1.55 (*s*, 1 H); 1.63–1.72 (*m*, 1 H); 2.01–2.30 (*m*, 2 H); 3.40 (*dd*, $J = 11.7$, 8.9, 1 H); 3.71 (*dd*, $J = 11.7$, 6.4, 1 H); 5.03 (*ddt*, $J = 10.7$, 9.3, 1.4, 1 H); 5.42 (*dtd*, $J = 10.8$, 7.2, 1.0, 1 H). ^{13}C-NMR ($CDCl_3$): 12.3 (*q*); 13.8 (*q*); 13.9 (*d*); 20.8 (*t*); 22.4 (*d*); 27.3 (*t*); 31.8 (*t*); 63.8 (*t*); 127.8 (*d*); 132.2 (*d*). MS: 154 (7, M^+), 136(2), 93(14), 93(14), 81(49), 67(100), 57(15), 54(449). HR-MS: 154.1346 ($C_{10}H_{18}O^+$; calc. 154.1358).

cis-*(1S,2S)-2-[(Z)-hex-1-enyl]cyclopropane-1-carbaldehyde* (**10**). To the orange suspension of PCC (1.28 g, 5.92 mmol), powdered, activated molecular sieves (460 mg), and NaOAc (139 mg, 1.69 mmol) in CH_2Cl_2 (20 ml), at 0°, **9** (435 mg, 2.82 mmol) in CH_2Cl_2 (5 ml) was added dropwise. The mixture was stirred at r.t. for 1 h. The black suspension was diluted with Et_2O (30 ml) and filtered through *Celite*, then through *Florisil*. The residue was extracted repeatedly with Et_2O. The filtrate was concentrated, and the crude product was purified by CC (silica gel; hexane/AcOEt 95 : 5): **10** (380 mg, 87%). Colorless oil. $[\alpha]_D^{20} = +233$ ($c = 0.6$, CH_2Cl_2) ([35]: $[\alpha]_D^{22} = -245$ ($c = 0.62$, CH_2Cl_2) for (−)-isomer). IR (KBr): 2932–2855*w*, 2742*w*, 1703*s*, 1458*s*. ^{1}H-NMR (200 MHz, $CDCl_3$): 0.81–0.95 (*m*, 1 H); 0.90 (*t*, $J = 7.0$, 3 H); 1.20–1.50 (*m*, 6 H); 1.98–2.18 (*m*, 2 H); 2.24–2.36 (*m*, 1 H); 5.29 (*ddt*, $J = 10.7$, 8.8, 1.5, 1 H); 5.51 (*dtd*, $J = 10.8$, 7.4, 1.2, 1 H); 9.23 (*d*, $J = 5.6$, 1 H). ^{13}C-NMR: 13.9 (*q*); 15.3 (*t*); 21.6 (*d*); 22.3 (*t*); 27.3 (*t*); 30.1 (*d*); 31.4 (*t*); 125.3 (*d*); 133.7 (*d*); 200.9 (*d*). MS: 152 (4, M^+), 123(9), 109(16), 95(14), 95(34), 81(62), 69(25), 67(100), 55(41). HR-MS: 152.1195 ($C_{10}H_{16}H^+$; calc. 152.1201).

cis-*(1R,2S)-1-Ethenyl-2-[(Z)-hex-1-enyl]cyclopropane* (**11**). To a suspension of Ph_3PCH_3Br (964 mg, 2.7 mmol) in Et_2O, at 0°, NaHDMS (2.7 ml, 1M in hexane, 2.7 mmol) was added with stirring. The suspension was cooled to $-78°$, and **10** (128 mg, 1.5 mmol) in Et_2O (5 ml) was added dropwise. After 15 min, the mixture was allowed to warm up to r.t. It was filtered through *Celite* and concentrated: **11** (220 mg, 98%). Colorless liquid after CC (silica gel; pentane). $[\alpha]_D^{20} = +118.8$ ($c = 1.68$, CH_2Cl_2) ([35]: $[\alpha]_D^{22} = -124.8$ ($c = 2.35$, CCl_4) for (−)-isomer; [36a]: $[\alpha]_D^{25} = +115.3$ ($c = 0.89$, CCl_4); $[\alpha]_D^{25} = -117.6$ ($c = 2.4$, CCl_4) for (−)-isomer). IR (NaCl): 3075*w*, 2954*w*, 1628*w*, 1460*w*, 982*s*, 891*s*. ^{1}H-NMR (400 MHz, $CDCl_3$): 0.51–0.60 (*m*, 1 H); 0.90 (*t*, $J = 7.1$, 3 H); 1.11–1.19 (*m*, 1 H); 1.24–1.43 (*m*, 4 H); 1.65–1.77 (*m*, 1 H); 1.78–1.89 (*m*, 1 H); 4.97 (*ddd*, $J = 10.3$, 2.0, 0.7, 1 H); 5.07 (*ddt*, $J = 10.8$, 9.2, 1.5, 1 H); 5.14 (*ddd*, $J = 17.0$, 2.0, 0.7, 1 H); 5.43 (*dtd*, $J = 10.8$, 9.2, 1.5, 1 H); 5.55 (*ddd*, $J = 17.0$, 10.3, 8.6, 1 H). ^{13}C-NMR: 13.9 (*q*); 14.7 (*t*); 17.2 (*d*); 22.26 (*d*); 22.3 (*t*); 27.3 (*t*); 31.9 (*t*); 114.2 (*t*); 128.4 (*d*); 131.1 (*d*); 138.1 (*d*). MS: 150 (25, M^+), 107(19), 93(77), 80(51), 79(100), 67(22). HR-MS: 150.1403 ($C_{11}H_{18}^+$; calc. 150.1409).

(S)-6-Butylcyclohepta-1,4-diene (*=(+)-Dictyopterene C'*; **12**). Compound **11** (100 mg) was heated in degassed CCl_4 in a dry and sealed glass tube to 80° for 5 h. Evaporation of the solvent under reduced pressure (200 Torr): **12** (100 mg, quant.). Colorless oil. $[\alpha]_D^{22} = +15.4$ ($c = 0.30$, $CHCl_3$) ([35]: $[\alpha]_D^{22} = +17.1$ ($c = 0.32$, $CHCl_3$), $[\alpha]_D^{22} = -16.8$ ($c = 0.27$, $CHCl_3$) for (−)-isomer; [36a]: $[\alpha]_D^{25} = +15.1$ ($c = 0.69$, $CHCl_3$), $[\alpha]_D^{25} - 15.5$ ($c = 1.74$, $CHCl_3$) for (−)-isomer; [36c]: $[\alpha]_D^{16} = +15.12$ (liq.)). IR (film): 3015*m*, 2966*m*, 2942*m*, 2863*m*, 1653*w*, 1460*w*, 682*w*, 642*w*. ^{1}H-NMR (400 MHz, $CDCl_3$): 0.88–0.92 (*m*, 3 H); 1.23–1.44 (*m*, 6 H); 2.04–2.27 (*m*, 2 H); 2.43–2.53 (*m*, 1 H); 2.63–2.78 (*m*, 1 H); 2.90–3.12 (*m*, 1 H). 5.55–5.86 (*m*, 4 H). ^{13}C-NMR: 14.1 (*q*); 22.8 (*t*); 28.3 (*t*); 29.5 (*t*); 32.8 (*t*); 36.0 (*t*); 37.1 (*d*); 127.2 (*d*); 128.1 (*d*); 129.9 (*d*); 136.9 (*d*). MS: 150 (2.5, M^+), 137(12), 123(21), 197(31), 95(58), 82(73), 79(76), 58(94), 55(100), 52(26). HR-MS: 150.1419 ($C_{11}H_{18}^+$; calc.: 150.1409).

REFERENCES

[1] J. J. Mac Farlane, F. S. Shenstone, J. R. Vikery, *Nature (London)* **1957**, *179*, 830; b) F. Bohlmann, J. Jakuovic, L. Müller, A. Schuster, *Angew. Chem., Int. Ed. Engl.* **1981**, *20*, 292; c) J. Salaün, M. S. Baird, *Curr. Med. Chem.* **1995**, *2*, 511.

[2] M. S. Baird, in 'Houben-Weyl, Methods for Organic Chemistry', 4th edn., Thieme, Stuttgart, 1997, Vol. E17a, p. 140.

[3] M. S. Baird, in 'Houben-Weyl, Methods for Organic Chemistry', 4th edn., Thieme, Stuttgart, 1997, Vol. E17b, p. 114.

[4] a) D. Müller, G. Umbricht, B. Weber, A. Pfaltz, *Helv. Chim. Acta* **1991**, *74*, 232; b) R. E. Lowenthal, S. Masamune, *Tetrahedron Lett.* **1991**, *32*, 7373; c) D. A. Evans, K. A. Woerpel, M. M. Hinman, *J. Am. Chem. Soc.* **1991**, *113*, 726; d) K. Ito, T. Katsuki, *Tetrahedron Lett.* **1993**, *34*, 2661.
[5] a) H. L. M. Davies, D. K. Hutcheson, *Tetrahedron Lett.* **1993**, *34*, 7243; H. L. M. Davies, P. Bruzinski, D. H. Lake, N. Kong, M. J. Fall, *J. Am. Chem. Soc.* **1996**, *118*, 6897, H. M. L. Davies, D. G. Stafford, B. D. Doan, J. H. Houser, *ibid.* **1988**, *120*, 3326; b) E. J. Corey, T. G. Grant, *Tetrahedron Lett.* **1994**, *35*, 5373.
[6] M. P. Doyle, Q.-L. Zhou, C. Charnsabgavej, M. A. Longoria, M. A. McKervey, C. F. Garcia, *Tetrahedron Lett.* **1996**, *37*, 4129.
[7] P. Müller, C. Baud, D. Ene, S. Motallebi, M. P. Doyle, B. D. Brandes, A. B. Dyatkin, M. M. See, *Helv. Chim. Acta* **1995**, *78*, 459.
[8] a) M. I. Komendatov, G. N. Suvurowa, *J. Org. Chem. USSR* **1968**, *4*, 365; b) M. Franck-Neumann, M. Miesch, *Tetrahedron Lett.* **1982**, *23*, 1409; c) V. Sander, P. Weyerstahl, *Chem. Ber.* **1978**, *111*, 3879.
[9] a) M. Franck-Neumann, C. Dietrich-Buchecker, *Tetrahedron Lett.* **1980**, *21*, 671; b) M. A. Battiste, *ibid.* **1964**, 3795; c) J. E. Baldwin, K. A. Black, *J. Am. Chem. Soc.* **1984**, *106*, 1029.
[10] M. P. Doyle, R. E. Austin, A. S. Bailey, M. P. Dwyer, A. B. Dyatkin, A. V. Kalinin, M. M. Y. Kwan, S. Liras, C. J. Oalmann, R. J. Pieters, M. N. Protopopova, C. E. Raab, G. H. P. Roos, Q.-L. Zhou, S. F. Martin, *J. Am. Chem. Soc.* **1995**, *117*, 5763; M. P. Doyle, R. J. Pieters, S. F. Martin, R. E. Austin, C. J. Oalmann, P. Müller, *ibid.* **1991**, *113*, 1423; P. Müller, C. Baud, D. Ene, S. Motallebi, M. P. Doyle, B. D. Brandes, A. B. Dyatkin, M. M. See, *Helv. Chim. Acta* **1995**, *78*, 459.
[11] S. F. Martin, R. E. Austin, C. J. Oalman, *Tetrahedron Lett.* **1990**, *31*, 4731; M. P. Doyle, R. E. Austin, A. S. Bailey, M. P. Dwyer, A. B. Dyatkin, A. V. Kalinin, M. M. Y. Kwan, S. Liras, C. J. Oalman, R. J. Pieters, M. N. Protopopova, C. E. Raab, G. H. P. Roos, Q.-L. Zhou, S. F. Martin, *J. Am. Chem. Soc.* **1995**, *117*, 5763.
[12] C. Piqué, B. Fähndrich, A. Pfaltz, *Synlett* **1995**. 491.
[13] M. P. Doyle, W. R. Winchester, M. N. Protopopova, A. P. Kazala, L. J. Westrum *Org. Synth.* **1995**, *73*, 13.
[14] a) M. P. Doyle, M. Protopopova, P. Müller, D. Ene, E. A. Shapiro, *J. Am. Chem. Soc.* **1994**, *116*, 8492; M. N. Protopopova, M. P. Doyle, P. Müller, D. Ene, *ibid.* **1992**, *114*, 2755; b) H. Imogaï, J.-C. Rossier, P. Müller, Abstracts 36th IUPAC Congress, Geneva, 1997, *Chimia* **1997**, *51*, 454.
[15] H. Imogaï, P. Müller, Abstracts Fall Meeting New Swiss Chemical Society, Lausanne, 1997, *Chimia* **1997**, *51*, 632.
[16] P. Camps, J. Cardellach, J. Font, R. M. Ortuño, O. Ponsati, *Tetrahedron* **1982**, *38*, 2395; N. Hanafi, R. M. Ortuño, *Tetrahedron: Asymmetry* **1994**, *9*, 1657.
[17] a) M. Es-Sayed, P. Devine, L. E. Burgess, A. de Mejere, A. J. Meyers, *J. Chem. Soc., Chem. Commun.* **1995**, *141*; b) A. M. P. Koskinen, L. Munoz, *J. Org. Chem.* **1993**, *58*, 879; c) P. Klaus, H. U. Reissig, *J. Prakt. Chem./Chem. Ztg.* **1995**, *55*, 337; d) R. Galeazzi, G. Mobbili, M. Orena, *Tetrahedron: Asymmetry* **1997**, *8*, 133.
[18] S. F. Martin, R. E. Austin, C. J. Oalmann, W. R. Baker, S. L. Condon, E. DeLara, S. H. Rosenberg, K. P. Spina, H. H. Stein, J. J. Cohen, H. D. Kleinert, *J. Med. Chem.* **1992**, *35*, 1710; W. R. Baker, H.-S. Jae, S. F. Martin, S. L. Condon, H. H. Stein, J. Cohen, H. D. Kleinert, *Bioorg. Med. Chem. Lett.* **1992**, *2*, 1045.
[19] H. S. Sommer, *Tetrahedron* **1990**, *46*, 2231; A. B. Charrette, B. Côté, *J. Am. Chem. Soc.* **1995**, *117*, 12721.
[20] J. M. Jiménez, J. Rifé, R. M. Ortuño, *Tetrahedron: Asymmetry* **1996**, *7*, 537.
[21] S. Kotha, *Tetrahedron* **1994**, *50*, 3650.
[22] M. Le Corre, A. Hercouet, B. Bessières, *Tetrahedron: Asymmetry* **1995**, *6*, 683.
[23] U. Zoller, D. Ben-Ishai, *Tetrahedron* **1975**, *31*, 863.
[24] U. Schmidt, A. Lieberknecht, J. Wild, *Synthesis* **1984**, 53.
[25] E. P. Prokof'ev, E. I. Karpeiskaya, *Tetrahedron Lett.* **1979**, *8*, 737.
[26] H. D. Flack, *Acta Crystallogr., Sect. A* **1983**, *39*, 876; G. Bernardinelli, H. D. Flack, *ibid.* **1985**, *41*, 500.
[27] a) J. A. Pettus, R. E. Moore, *J. Chem. Soc., Chem. Commun.* **1970**, 1093; J. A. Pettus, Jr., R. E. Moore, *J. Am. Chem. Soc.* **1971**, *93*, 3087; R. E. Moore, J. A. Pettus, J. Mistysyn, *J. Org. Chem.* **1974**, *39*, 2201; R. E. Moore, in 'Marine Natural Products', Ed. P. J. Scheuer, Academic Press, New York, 1978, Chapt. 2; b) W. D. Wirth, I. Fisher, W. Boland, D. Icheln, T. Runge, W. A. König, J. Philips, M. Clayan, *Helv. Chim. Acta* **1992**, *75*, 734.
[28] R. E. Moore, *Acc. Chem. Res.* **1977**, *10*, 40.
[29] a) E. Vogel, *Angew. Chem., Int. Ed. Engl.* **1963**, *2*, 1; b) W. Pickenhagen, F. Näf, G. Ohloff, P. Müller, J.-C. Perlberger, *Helv. Chim. Acta* **1973**, *56*, 1868; c) J. J. Gaiewski, C. M. Hawkins, J. I. Jimenez, *J. Org. Chem.* **1990**, *55*, 674; d) T. Hudlicky, R. Fan, J. W. Reed, K. G. Gadamesetti, *Org. React.* **1992**, *41*, 1.

[30] G. Ohloff, W. Pickenhagen, *Helv. Chim. Acta* **1969**, *52*, 880.
[31] a) A. Ali, D. Sarantakis, B. Weinstein, *J. Chem. Soc., Chem. Commun*. **1971**, 940; b) L. Jaenicke, T. Akintobi, D. G. Müller, *Angew. Chem., Int. Ed. Engl*. **1971**, *10*, 492; L. Jaenicke, T. Akintobi, F.-J. Marner, *Justus Liebigs Ann. Chem*. **1973**, 1252.
[32] M. P. Schneider, M. Goldbach, *J. Am. Chem. Soc*. **1980**, *102*, 6114.
[33] D. Romo, J. L. Romine, W. Midura, A. I. Meyers, *Tetrahedron* **1990**, *46*, 4951.
[34] F. Colobert, J.-P. Genet, *Tetrahedron Lett*. **1985**, *26*, 2779.
[35] D. Grandjean, P. Pale, J. Chuche, *Tetrahedron* **1991**, *47*, 1215.
[36] a) T. Schotten, W. Boland, L. Jaenicke, *Tetrahedron Lett*. **1986**, *27*, 2349; b) *Helv. Chim. Acta* **1985**, *68*, 1186; S. Panthe-Becker, G. Pohnert, I. Fischer-Lui, W. Boland, *Tetrahedron* **1995**, *51*, 7927; c) M. Asaoka, K. Kobayashi, H. Takei, *Bull Chem. Soc. Jpn.* **1994**, *67*, 1141.
[37] P. Müller, C. Baud, D. Ene, S. Motallebi, M. P. Doyle, B. D. Brandes, A. B. Dyatkin, M. M. See, *Helv. Chim. Acta* **1995**, *78*, 459; M. P. Doyle, W. R. Winchester, M. N. Protopopova, P. Müller, G. Bernardinelli, D. Ene, S. Motallebi, *Helv. Chim. Acta* **1993**, *76*, 2227.
[38] P. Main, S. J. Fiske, S. E. Hull, L. Lessinger, G. Germain, J.-P. Declercq, M. M. Woolfson, A System of Computer Programs for the Automatic Solution of Crystal Structures from X-Ray Diffraction Data 1987 Univs. of York, England, and Louvain-la-Neuve, Belgium.
[39] S. R. Hall, H. D. Flack, J. M. Stewart, Eds. XTAL3.2 User's Manual, 1992, Universities of Western Australia, Geneva and Maryland.
[40] C. K. Johnson, ORTEP II; Report ORNL-5138; Oak Ridge National Laboratory: Oak Ridge, TN 1976.
[41] E. Blanc, D. Schwarzenbach, H. D. Flack, *J. Appl. Crystallogr.* **1991**, *24*, 1035.

Received July 3, 1998