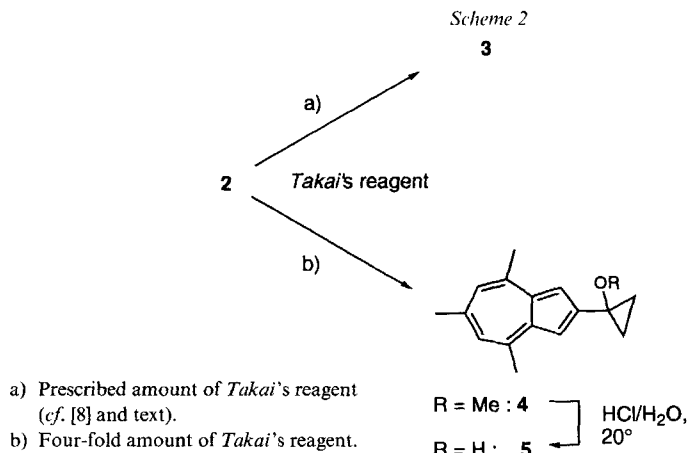




of 1 mol-equiv. of a carboxylate, 2.2 mol-equiv. of  $\text{CH}_2\text{Br}_2$  and 4.0 mol-equiv. of  $\text{TiCl}_4$  in the presence of 9 mol-equiv. of Zn and 8 mol-equiv. of *N,N,N',N'*-tetramethylethylenediamine (TMEDA) have to be applied.

We were quite surprised to find that an increase in the molar amount of *Takai's* reagent per mol of **2** led to the formation of a new product **4** which was formed almost quantitatively, when a four-fold excess of the prescribed amount of the reagent was used (*Scheme 2*)<sup>5</sup>.



The structure of the new product turned out to be that of the corresponding cyclopropyl methyl ether **4** which could easily be hydrolyzed to cyclopropanol **5**. The structure of this compound was established by an X-ray crystal-structure analysis (see *Exper. Part*). One can speculate that **4** is a follow-up product of **3**. However, treatment of **3** with *Takai's* reagent did not lead in our hands to the formation of **4**. Furthermore, we checked that the reaction of **1** with an excess of *Takai's* or *Tebbe's* reagent did not yield a corresponding cyclopropane derivative, but stopped at the stage of 2-isopropenyl-4,6,8-trimethylazulene (cf. [7]). These observations may be considered as an indication that the cyclopropanization reaction of **2** occurs in two consecutive methylenation steps of intermediates linked with their O-atoms to an appropriate Ti-ylide complex.

The cyclopropanization reaction of methyl carboxylates with *Takai's* reagent seems to be quite general as is demonstrated by the examples delineated in *Scheme 3*.

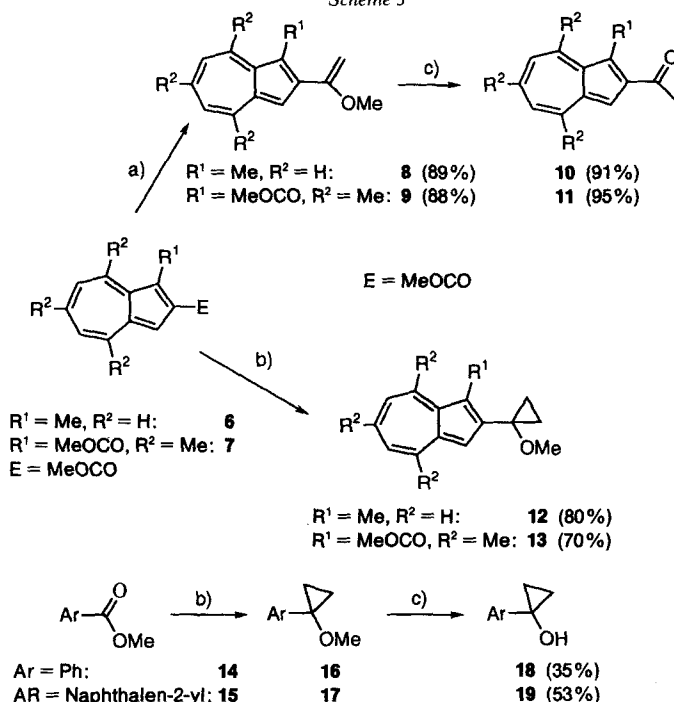
The reaction of the azulene-2-carboxylates **6** and **7** with the appropriate amount of *Takai's* reagent yielded the enol ethers **8** and **9**<sup>6</sup>), or the corresponding cyclopropyl methyl ethers **12** and **13**, respectively. In the case of the azulene-1,2-dicarboxylate **7**, only the MeOCO group at C(2) underwent the methylenation reactions<sup>7</sup>). Further examples are the cyclopropanization reaction of methyl benzoate (**14**) and methyl 2-naphthoate (**15**)

<sup>5</sup>) The same result was achieved, when 2 mol-equiv. of *Tebbe's* reagent from Aldrich® was employed, provided that the reagent was taken from a freshly opened bottle.

<sup>6</sup>) Compounds **8** and **9** lead, on hydrolysis, to **10** and **11**, respectively.

<sup>7</sup>) Ethyl 2,4,6,8-tetramethylazulene-1-carboxylate reacts also with the four-fold amount of *Takai's* reagent in THF at 0°. However, no cyclopropane derivative could be isolated from the reaction mixture.

Scheme 3

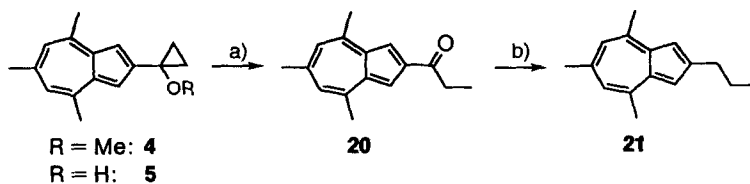


a), b) See Scheme 2. c) 2N HCl.

with the four-fold amount of *Takai's* reagent. However, no cyclopropane derivative could be obtained from the reaction of methyl 2-phenylacetate with *Takai's* reagent<sup>8)</sup>.

The formation of cyclopropyl methyl ethers in the methylenation reaction of methyl carboxylates with Ti-based methanides allows the synthesis of further products. For example, the acid-catalyzed rearrangement of cyclopropyl compounds **4** and **5** leads to the formation of 1-(4,6,8-trimethylazulen-2-yl)propan-1-one (**20**) which, on reduction with  $\text{Et}_3\text{SiH}$  in  $\text{CF}_3\text{COOH}$  (TFA) (*cf.* also [10]) yields the corresponding 2-propylazulene **21** (Scheme 4). Both steps can be combined, *i.e.*, treatment of **4** or **5** with  $\text{Et}_3\text{SiH}$  in  $\text{CF}_3\text{COOH}$  leads directly to **21** with **20** as intermediate.

Scheme 4



a) TFA, 25°. b)  $\text{Et}_3\text{SiH}$ /TFA, 60°.

<sup>8)</sup> We cannot exclude at the moment that our workup procedure destroys the expected 1-benzylcyclopropyl methyl ether.

We thank Dr. A. Linden for the X-ray crystal-structure analysis of **5**, Prof. M. Hesse and his coworkers for mass spectra, Prof. W. von Philipsborn and his coworkers for NMR support and  $^1\text{H}$ -NOE measurements, and H. Frohofer for elemental analysis. The financial support of this work by the Swiss National Science Foundation is gratefully acknowledged.

### Experimental Part

**General.** See [11]. TLC on silica gel on aluminium foils (silica gel 60 F 254, Merck; layer thickness 0.2 mm); eluant: hexane/Et<sub>2</sub>O 1:1. UV Spectra: on a Perkin-Elmer spectrophotometer (model Lambda 9). Unless otherwise stated, all  $^1\text{H}$ -NMR spectra were measured on a Bruker instrument (model AC 300) in CDCl<sub>3</sub> as solvent.

**General Procedure for the Methylenation of Methyl Carboxylates Leading to Ethenyl Methyl or Cyclopropyl Methyl Ethers.** The reagent for the methylenation was prepared as described by Takai and coworkers [8] (see also [9]). For the formation of the ethenyl methyl ethers, 2.2 mmol of CH<sub>2</sub>Br<sub>2</sub> (Fluka, puriss.) were applied per mmol of the methyl carboxylates. The synthesis of the cyclopropyl methyl ethers was realized with 8.8 mmol CH<sub>2</sub>Br<sub>2</sub> per mmol of the methyl carboxylates. The reaction mixtures were stirred for 3 h at 25° and then poured on ice in 2N NaOH. The resulting mixtures were filtered over Celite and the filter cakes thoroughly washed with CH<sub>2</sub>Cl<sub>2</sub>. The CH<sub>2</sub>Cl<sub>2</sub> phases were separated and dried (MgSO<sub>4</sub>). The solvent was distilled off and the residue subjected to CC (silica gel; hexane/Et<sub>2</sub>O 1:1). For the separation of ethenyl methyl esters, silica gel was pretreated with Et<sub>3</sub>N. Crystalline compounds were recrystallized from hexane/Et<sub>2</sub>O. Liquid compounds were further purified by bulb-to-bulb distillation *in vacuo*.

**1. Ethenyl Methyl Ethers.** – 1.1. 2-(1-Methoxyethenyl)-4,6,8-trimethylazulene (**3**). From 0.88 mmol of methyl 4,6,8-trimethylazulene-2-carboxylate (**2**) [7], 0.85 mmol (97%) of **3** were obtained. Blue crystals from hexane/Et<sub>2</sub>O. M.p. 124–125°.  $R_f$  0.35.  $^1\text{H}$ -NMR<sup>b</sup>: 7.46 (s, H–C(1,3)); 7.03 (s, H–C(5,7)); 5.01 (d,  $^2J = 2.4$ , H<sub>A</sub>–C(2')); 4.39 (d,  $^2J = 2.4$ , H<sub>B</sub>–C(2')); 3.83 (s, MeO); 2.85 (s, Me–C(4,8)); 2.60 (s, Me–C(6)).

The hydrolysis of **3** with 2N HCl in Et<sub>2</sub>O yielded pure 4,6,8-trimethylazulene-2-yl methyl ketone (**1**) (cf. [1]).

1.2. 2-(1-Methoxyethenyl)-1-methylazulene (**8**). From 0.76 mmol of methyl 1-methylazulene-2-carboxylate (**6**) [12], 0.68 mmol (89%) of **8** were obtained. Blue oil.  $R_f$  0.36.  $^1\text{H}$ -NMR: 8.24 (d,  $J(8,7) = 9.9$ , H–C(8)); 8.18 (d,  $J(4,5) = 8.9$ , H–C(4)); 7.48 (t,  $J(6,5) \approx J(6,7) = 9.8$ , H–C(6)); 7.48 (s, H–C(3)); 7.08 (t,  $J(7,6) \approx J(7,8) = 9.9$ , H–C(7)); 7.04 (t,  $J(5,6) \approx J(5,4) = 9.9$ , H–C(5)); 4.85 (d,  $^2J = 2.6$ , H<sub>A</sub>–C(2')); 4.67 (d,  $^2J = 2.6$ , H<sub>B</sub>–C(2')); 3.82 (s, MeO); 2.73 (s, Me).

1.2.1. Methyl 1-Methylazulene-2-yl Ketone (**10**). In 2N HCl (20 ml), **8** (0.10 g, 0.50 mmol) was dissolved and extracted twice with Et<sub>2</sub>O (30 ml). The extracts were dried (MgSO<sub>4</sub>), and the solvent distilled off. After purification by CC, 0.085 g (91%) of **10** was obtained. Green oil.  $R_f$  0.50. UV (hexane):  $\lambda_{\text{max}}$  367 (3.75), 354 (4.06), 339 (4.04), 286 (4.98), 241 (4.54);  $\lambda_{\text{min}}$  344 (4.00), 331 (4.01), 252 (4.44), 226 (4.37). IR (KBr): 2922m, 1663s, 1574m, 1420m, 1376m, 1355m, 1280m, 1233s, 1203s, 1102m, 930m, 797s, 740s.  $^1\text{H}$ -NMR (C<sub>6</sub>D<sub>6</sub>): 7.97 (d, H–C(8),  $J(8,7) = 9.8$ ); 7.88 (d,  $J(4,5) = 9.5$ , H–C(4)); 7.34 (s, H–C(3)); 7.08 (t,  $J(6,5) \approx J(6,7) = 9.8$ , H–C(6)); 6.60 (t,  $J(7,6) \approx J(7,8) = 9.9$ , H–C(7)); 6.59 (t,  $J(5,6) \approx J(5,4) = 9.9$ , H–C(5)); 2.89 (s, Me–C(1)); 2.41 (s, MeCO).

1.3. Methyl 2-(1-Methoxyethenyl)-4,6,8-trimethylazulene-1-carboxylate (**9**). From 1.17 mmol of dimethyl 4,6,8-trimethylazulene-1,2-dicarboxylate (**7**), 1.03 mmol (88%) of **9** were obtained. Red-violet crystals from hexane/Et<sub>2</sub>O. M.p. 95–96°.  $R_f$  0.36.  $^1\text{H}$ -NMR: 7.36 (s, H–C(3)); 7.10 (s, H–C(5)); 7.08 (s, H–C(7)); 4.80 (d,  $^2J = 2.6$ , H<sub>A</sub>–C(2')); 4.39 (d,  $^2J = 2.6$ , H<sub>B</sub>–C(2')); 3.92 (s, MeOCO); 3.75 (s, MeO–C(1')); 2.83 (s, Me–C(4,8)); 2.60 (s, Me–C(6)).

1.3.1. Methyl 2-Acetyl-4,6,8-trimethylazulene-1-carboxylate (**11**). In 2N HCl (20 ml) **9** (0.10 g, 0.35 mmol) was dissolved and extracted twice with Et<sub>2</sub>O (40 ml). The extracts were dried (MgSO<sub>4</sub>) and the solvent distilled off. After purification by CC, 0.090 g (95%) of **11** was obtained. Blue-violet crystals from hexane/Et<sub>2</sub>O. M.p. 133–134°.  $R_f$  0.15.  $^1\text{H}$ -NMR: 7.61 (s, H–C(3)); 7.16 (s, H–C(5)); 7.13 (s, H–C(7)); 4.00 (s, MeOCO); 2.91 (s, Me–C(8)); 2.86 (s, Me–C(4)); 2.68 (s, MeCO–C(2)); 2.63 (s, Me–C(6)). Anal. calc. for C<sub>17</sub>H<sub>18</sub>O<sub>3</sub> (270.33): C 75.53, H 6.71; found: C 75.41, H 6.58.

**2. Cyclopropyl Methyl Ethers and Cyclopropanols.** – 2.1. 2-(1-Methoxycyclopropyl)-4,6,8-trimethylazulene (**4**). From 1.75 mmol of **2**, 1.67 mmol (95%) of **4** were obtained. Red liquid.  $R_f$  0.35.  $^1\text{H}$ -NMR: 7.13 (s, H–C(1,3)); 7.06 (s, H–C(5,7)); 3.48 (s, MeO); 2.83 (s, Me–C(4,8)); 2.62 (s, Me–C(6)); 1.40 (AA' of AA'BB', H<sub>A</sub>–C(2',3')); 1.20 (BB' of AA'BB', H<sub>B</sub>–C(2',3')).

<sup>b</sup>) For clarity, the locants of the substituent(s) are primed.

2.2. *1-(4,6,8-Trimethylazulen-2-yl)cyclopropanol (5)*. From 1.67 mmol of **4**, after hydrolysis in 2N HCl, 1.67 mmol (99%) of **5** were obtained. Pink needles from hexane/Et<sub>2</sub>O. M.p. 130°. *R*<sub>f</sub> 0.18. UV (hexane):  $\lambda_{\max}$  375 (3.15), 358 (3.20), 343 (3.14), 315 (sh, 3.33), 300 (4.23), 289 (sh, 4.17), 249 (3.85);  $\lambda_{\min}$  369 (2.90), 351 (3.09), 372 (3.03), 261 (3.13), 208 (3.51). IR (CH<sub>2</sub>Cl<sub>2</sub>): 3684s, 3585m, 2978s, 2872s, 1605m, 1383m, 1215m, 1113s, 1065m, 896s. <sup>1</sup>H-NMR: 7.10 (s, H-C(1',3')), 7.06 (s, H-C(5',7')); 2.83 (s, Me-C(4',8')); 2.61 (s, Me-C(6')); 1.45 (AA' of AA'BB', H<sub>A</sub>-C(2,3)); 1.24 (BB' of AA'BB', H<sub>B</sub>-C(2,3)). EI-MS: 227 (29, [M + 1]<sup>+</sup>), 226 (100, M<sup>+</sup>), 211 (63), 197 (34), 183 (19), 170 (10), 169 (25), 153 (15), 152 (11), 115 (13), 77 (11), 63 (11), 57 (14), 55 (60), 51 (18).

*X-Ray Structure Analysis of 5*. The structure of **5** has been solved without unusual features. There are two symmetry-independent molecules in the asymmetric unit. However, there are no significant geometrical differences between the molecules. The independent molecules are linked to each other by intermolecular H-bonds. These interactions form infinite one-dimensional chains run parallel to *x*-axis.

2.3. *2-(1-Methoxycyclopropyl)-1-methylazulene (12)*. From 1.01 mmol of **7**, 0.81 mmol (80%) of **12** were obtained. Blue liquid. *R*<sub>f</sub> 0.32. UV (hexane):  $\lambda_{\max}$  350 (3.43), 337 (3.38), 286 (4.56), 242 (4.07), 213 (sh, 3.97);  $\lambda_{\min}$  344 (3.34), 322 (3.29), 254 (3.98), 224 (3.91). IR (CH<sub>2</sub>Cl<sub>2</sub>): 3056s, 2989s, 2933s, 1575m, 1447s, 1421m, 1395m, 1351m, 1292m, 1229s, 1064s, 774m. <sup>1</sup>H-NMR: 8.24 (d, *J*(8,7) = 9.9, H-C(8)); 8.15 (d, *J*(4,5) = 8.9, H-C(4)); 7.50 (t, *J*(6,7) ≈ *J*(6,5) = 9.8); 7.15 (s, H-C(3)); 7.08 (t, *J*(7,6) ≈ *J*(7,8) = 9.9, H-C(7)); 7.04 (t, *J*(5,6) ≈ *J*(5,4) = 9.9, H-C(5)); 3.19 (s, MeO); 2.75 (s, Me); 1.25 (AA' of AA'BB', H<sub>A</sub>-C(2',3')); 1.07 (BB' of AA'BB', H<sub>B</sub>-C(2',3')). EI-MS: 213 (4, [M + 1]<sup>+</sup>), 212 (9, M<sup>+</sup>), 197 (15), 169 (13), 167 (9), 165 (18), 155 (100), 153 (13), 152 (10), 141 (32), 139 (21), 128 (12), 115 (49), 71 (11), 63 (17), 57 (15), 55 (19), 51 (11).

2.4. *Methyl 2-(1-Methoxycyclopropyl)-4,6,8-trimethylazulene-1-carboxylate (13)*. From 1.06 mmol of **6**, 0.74 mmol (70%) of **13** were obtained. Red crystals from hexane/Et<sub>2</sub>O. M.p. 111–112°. *R*<sub>f</sub> 0.25. UV (hexane):  $\lambda_{\max}$  374 (sh, 3.37), 358 (3.66), 302 (4.60), 249 (4.30), 230 (4.21);  $\lambda_{\min}$  336 (3.60), 264 (3.75), 234 (4.20), 208 (4.09). IR (CH<sub>2</sub>Cl<sub>2</sub>): 2949m, 1714s, 1581m, 1500w, 1436s, 1389m, 1375m, 1348w, 1216s, 1164m, 1140m, 1062m, 1029m. <sup>1</sup>H-NMR: 7.12 (s, H-C(5,7)); 6.97 (s, H-C(3)); 3.95 (s, MeOCO); 3.20 (s, MeO); 2.86 (s, Me-C(8)); 2.83 (s, Me-C(4)); 2.61 (s, Me-C(6)); 1.23 (AA' of AA'BB', H<sub>A</sub>-C(2',3')); 1.15 (BB' of AA'BB', H<sub>B</sub>-C(2',3')). EI-MS: 299 (9, [M + 1]<sup>+</sup>), 298 (52, M<sup>+</sup>), 283 (46), 268 (36), 266 (18), 255 (19), 251 (32), 240 (20), 239 (100), 237 (20), 223 (48), 209 (47), 197 (27), 196 (19), 195 (25), 193 (40), 181 (27), 180 (24), 179 (56), 178 (51), 167 (27), 166 (28), 165 (91), 153 (45), 152 (63), 141 (26), 115 (28), 59 (26), 55 (31).

2.5. *1-Phenylcyclopropanol (18; cf. [13])*. From 1.49 mmol of methyl benzoate (**14**), 0.52 mmol (35%) of **18** were obtained. Colorless liquid. *R*<sub>f</sub> 0.42. <sup>1</sup>H-NMR: 7.3–7.1 (m, arom. H); 2.68 (br. s, OH); 1.27 (AA' of AA'BB', H<sub>A</sub>-C(2,3)); 1.07 (BB' of AA'BB', H<sub>B</sub>-C(2,3)).

2.6. *1-(Naphthalen-2-yl)cyclopropanol (19)*. From 2.15 mmol of methyl 2-naphthoate (**15**), 1.14 mmol (53%) of **19** were obtained. Colorless crystals from hexane/Et<sub>2</sub>O. M.p. 86–87°. *R*<sub>f</sub> 0.32. UV (hexane):  $\lambda_{\max}$  285 (sh, 2.63), 276 (2.77), 226 (3.86);  $\lambda_{\min}$  251 (2.56). <sup>1</sup>H-NMR: 7.9–7.7 (m, 4 arom. H); 7.55–7.40 (m, 2 arom. H); 7.31 (dd, <sup>3</sup>*J* = 8.6, <sup>4</sup>*J* = 1.7, 1 arom. H); 2.52 (br. s, OH); 1.35 (AA' of AA'BB', H<sub>A</sub>-C(2,3)); 1.17 (BB' of AA'BB', H<sub>B</sub>-C(2,3)). EI-MS: 185 (25, [M + 1]<sup>+</sup>), 184 (100, M<sup>+</sup>), 167 (13), 155 (25), 144 (10), 128 (16).

**3. Reduction of Cyclopropanol 5**. – Compound **5** (0.05 g, 0.22 mmol) was dissolved in TFA (50%, 2 ml) and stirred during 2 h at r.t. After neutralization with 2N NaOH, the mixture was extracted with Et<sub>2</sub>O. After usual workup, *1-(4,6,8-trimethylazulen-2-yl)propan-1-one (20)* (0.04 g, 80%) was purified by CC. Blue crystals from hexane/Et<sub>2</sub>O. M.p. 130–131°. *R*<sub>f</sub> 0.29. <sup>1</sup>H-NMR: 7.73 (s, H-C(1',3')); 7.08 (s, H-C(5',7')); 3.16 (q, *J* = 7.7); 2.89 (s, Me-C(4,8)); 2.63 (s, Me-C(6)); 1.03 (t, *J* = 7.7).

3.1. *4,6,8-Trimethyl-2-propylazulene (21)*. Compound **5** (0.05 g, 0.22 mmol) was dissolved in TFA (4 ml), and Et<sub>3</sub>SiH (2 ml) was added. The mixture was stirred during 16 h at 60°. The mixture was poured on chopped ice and neutralized with powdered K<sub>2</sub>CO<sub>3</sub>. After extraction with Et<sub>2</sub>O and usual workup, **20** (0.010 g, 20%) and **21** (0.025 g, 51%) were separated by CC. Data of **21**: red liquid. *R*<sub>f</sub> 0.50. <sup>1</sup>H-NMR: 7.14 (s, H-C(1,3)); 7.02 (s, H-C(5,7)); 2.83 (s, Me-C(4,8)); 2.60 (s, Me-C(6)); 1.83 (t, *J* = 7.7, Pr-C(6)); 1.41 (sext., *J* = 7.7, Pr-C(6)); 1.03 (t, *J* = 7.7, Pr-C(6)). EI-MS: 212 (15, M<sup>+</sup>), 198 (11), 185 (11), 184 (63), 183 (32), 169 (32), 167 (15), 165 (25), 160 (13), 155 (11), 153 (26), 152 (23), 141 (15), 129 (14), 128 (22), 115 (23), 97 (15), 95 (12), 92 (14), 91 (100), 83 (23), 81 (16), 71 (21), 69 (31), 65 (219), 57 (42), 55 (43).

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