New Sesquiterpene Carbonimidic Dichlorides and Related Compounds from the Sponge *Stylotella aurantium*

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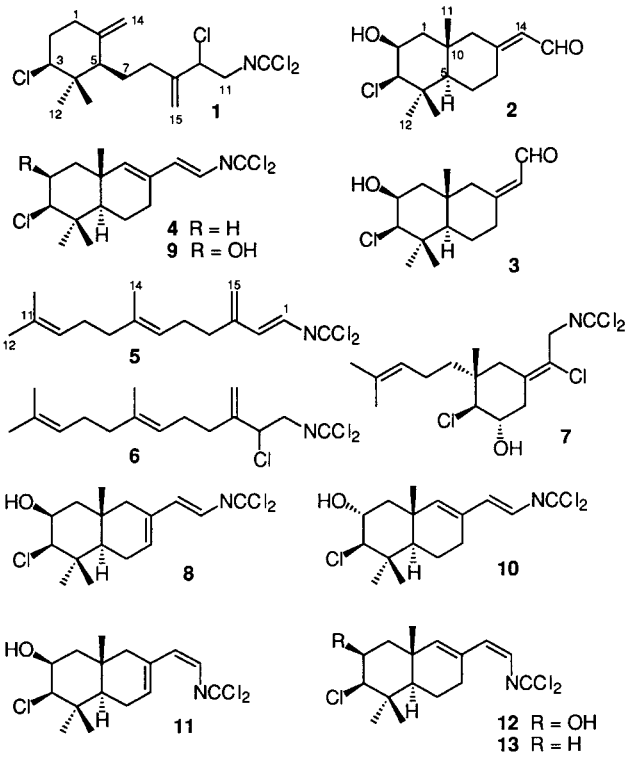
Five new sesquiterpenes (**1**−**5**) having a carbonimidic dichloride or an aldehyde function have been isolated, together with seven known related compounds (**6**−**12**), from the sponge *Stylotella aurantium*. The structures of the new compounds were elucidated from spectral data. The absolute stereochemistry of the previously reported reticulidin A (**10**) was determined. Four of the new compounds showed cytotoxicity with a range of IC_{50} values of 0.1−1 μg/mL against several tumor cell lines.

We recently reported the isolation and structure elucidation of two new sesquiterpene carbonimidic dichlorides (**8**, **10**) from the nudibranch *Reticulidia fungia*.[1] Inasmuch as related compounds have earlier been described only from a few species of sponges,[2−6] it was evident that the nudibranch constituents originated from a sponge. However, we were unable to locate a plausible species in the vicinity of the nudibranch collection site on Irabu Island, Okinawa. More recently we examined cytotoxic constituents of a sponge collected from a coral reef of Iriomote Island, located 150 km west of Irabu, and later identified as *Stylotella aurantium*, the same species that yielded carbonimidic dichlorides in Australia.[6] Our sample also gave sesquiterpene carbonimidic dichlorides, including five new congeners (**1**−**5**), which were responsible for the cytotoxicity of the lipophilic extract of the sponge. As described earlier,[1] our interest in these compounds is twofold: their biological activity, such as cytotoxicity,[1] and biogenesis of the functionality.[6] In this note we describe the isolation and structures of the new members having this functionality (**1**, **4**, **5**) and two new related compounds (**2**, **3**).

A sample (90 g, wet wt) of *S. aurantium* Kelly-Borges and Bergquist (family Axinellidae) was extracted with acetone, and the concentrated extract was partitioned between ethyl acetate and water. The EtOAc extract (0.65 g) was separated on Si gel followed by preparative TLC and/or HPLC to afford sesquiterpenes **1**−**12** in yields ranging from 1.5 to 12.0 mg.

Compound **1**, $[\alpha]_D$ +4.5° (*c* 0.20, $CHCl_3$), was isolated as a colorless oil. The molecular formula $C_{16}H_{23}NCl_4$ was determined by observing a molecular ion at *m*/*z* 369 in ESIMS and by HREIMS at *m*/*z* 334.0870 ($[M - Cl]^+$). The presence of a carbonimidic dichloride functional group was inferred from a carbon signal at δ 127.0 s and also by IR absorption at 1655 cm^{-1}, as reported earlier.[2−6] The ^1H and ^{13}C NMR spectra of **1** indicated the presence of two exomethylenes [δ 4.66 s, 4.95 s, 5.07 s, 5.19 s; δ 109.2 t (C-14), 114.4 t (C-15), 145.6 s (C-6), 146.3 s (C-9)], two chlorine-bearing methines [δ 3.90 dd, 4.60 t; δ 62.2 d (C-10), 70.9 d (C-3)], a methylene bearing a nitrogen [δ 3.84 d; δ 59.3 t (C-11)], and two methyls [δ 0.84 s, 1.16 s; δ 15.9 q (C-12), 27.2 q (C-13)]. These data, together with the unsaturation requirement, suggested **1** to be monocyclic. Connectivity was made by interpreting 2D NMR (COSY, HMQC, HMBC) spectra. The presence of a six-membered ring was shown by COSY (H-1$\alpha\beta$/H-2$\alpha\beta$, H-2$\alpha\beta$/H-3, H-1α/H-5, H-1α/H-14a, H-1β/H-14b, and H-5/H-14ab) and HMBC data (H-1$\alpha\beta$/C-2,-3,-5,-6,-14, H-2$\alpha\beta$/C-1,-3,-4,-6, H-3/C-4,-12,-13, H-5/C-3,-4,-6,-8,-14, and H_3-12,-13/C-3,-4,-5). Connectivity between the ring and the terminal carbonimidic dichloride was also made by COSY (H-5/H-7ab,-8ab; H-7ab/H-8ab, H-8ab/H-15ab, H-10/H-11,-15b) and HMBC (H-10/C-15, H_2-11/C-16) cross-peaks. Relative stereochemistry in the ring was elucidated as shown by observing positive NOEs (H-3/H-5, H-3/H_3-12, H-7/H_3-13). The stereochemistry at C-10 remains to be solved.



Compound **2**, $[\alpha]_D$ +16° (*c* 0.13, $CHCl_3$), was obtained as a colorless glass. EIMS of **2** showed a molecular ion at *m*/*z* 270. High-resolution measurement of this peak gave a molecular formula $C_{15}H_{23}ClO_2$. The formula indicated four degrees of unsaturation. The NMR spectra displayed signals for three methyl singlets [δ 1.11 (H_3-12), 1.11 (H_3-13), 1.14 (H_3-11); δ 17.8 q, 23.9 t, 30.4 q], α,β-unsaturated aldehyde [δ 10.02 d; δ 127.5 d (C-14), 163.5 s (C-8), 190.1 d (C-15)], and two methines bearing a chlorine and/or a hydroxyl [δ 3.93 d, 4.18 q; δ 71.9 d (C-2), 76.3 d (C-3)]. The

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IR absorption band at 1666 cm^{-1} also indicated the presence of the α,β-unsaturated aldehyde. Comparison of these and 2D NMR data with those of reticulidin B (**8**) suggested that **2** consisted of a bicyclic portion similar to reticulidin B and an enal moiety instead of a carbonimidic dichloride as in **8**. The hydroxyl group was located at C-2 by a deuterium-induced shift experiment (Δδ −0.115), as before.[1] The double-bond geometry of the enal was assigned as *E* by positive NOEs between H-9 and H-14 and also between H-7β and H-15. Compound **2** had the same relative stereochemistry as **8** as confirmed by NOE observation (H-2/H-3, H-3/H-5). Because the aldehyde could be derived by hydrolysis of **8**, it was suspected that **2** might be an artifact formed during the isolation procedure. However, when **8** was treated with *p*-TsOH in aqueous THF (room temperature, 12 h), **8** was recovered with no signs of reaction, suggesting that **2** is, indeed, a natural product.

Compound **3**, $[\alpha]_D$ −28° (*c* 0.13, $CHCl_3$), had the same molecular formula, $C_{15}H_{23}ClO_2$, as **2** as determined by HREIMS. The ^{13}C NMR spectrum of **3** was almost identical to that of **2**, except for the signals for C-7 (Δδ 8.4) and C-9 (Δδ −8.6). In the ^1H NMR spectrum major differences between **3** and **2** were noted for the chemical shifts for H-7 (Δδ 0.21, −1.01), H-9 (−0.22, 1.00), H-14 (0.17), and H-15 (−0.07), suggesting a configurational difference around the double bond. Observation of positive NOEs (H-7β/H-14, H-9β/H-15) revealed the *Z*-configuration of the double bond. Relative stereochemistry on the bicyclic portion was the same as that of **2**, as confirmed by NOE measurements. The position of the hydroxyl group on C-2 was also confirmed by a deuterium-induced shift (Δδ −0.115).

Compound **4**, $[\alpha]_D$ +40° (*c* 0.13, $CHCl_3$), had the molecular formula $C_{16}H_{22}NCl_3$ (HREIMS, Δ +0.7 mmu). It contained a carbonimidic dichloride (1640 cm^{-1}; δ 124.0 s), two double bonds [δ 5.59 s (H-9), 6.51 d (H-14), 6.70 d (H-15); δ 128.9 d, 130.6 s, 137.7 d, 146.4 d], a chlorine-bearing methine (δ 3.75 dd; δ 72.4 d), and three methyls [δ 0.94 s (H-13), 1.03 s (H-11), 1.10 s (H-12); δ 16.6 q, 20.8 q, 28.9 q]. The structure of **4** was secured by COSY, HMQC, and HMBC data and also by comparison of these data with those of **9** and **13**.[4] The relative stereochemistry is based on the NOESY cross-peaks (H-3/H-2α, H-3/H-5, H-3/H_3-12, H-5/H_3-12, H_3-11/H_3-13) and on the similarity of NMR data to those of **13**.[4] Finally, the coupling constant $J_{14,15}$ (13.0 Hz) and NOEs between H-9 and H-14 and also between H-7β and H-15 were indicative of *E* geometry of the disubstituted double bond.

Because compound **5** decomposed during storage in an NMR tube, we failed to record mass spectral data. A plausible formula, $C_{16}H_{23}NCl_2$, could be deduced from NMR data. The ^1H NMR spectrum of **5** was composed of signals for two exomethylene protons [δ 5.19 and 5.23 s (H-15)], four vinyl protons [δ 5.09 t (H-10), 5.16 t (H-6), 6.62 d (H-2), and 6.87 d (H-1)], four methylenes [δ 1.99 t (H-8), 2.07 q (H-9), 2.23 q (H-5), 2.28 t (H-4)], and three vinyl methyls [δ 1.61 s (H-13), 1.61 s (H-14), 1.69 s (H-12)]. In addition to a characteristic signal at δ 125.2 s for $NCCl_2$, the ^{13}C NMR data, together with an HMQC experiment, confirmed the presence of the above functionalities. Comparison of these data with those of **6** suggested that **5** has a trans double bond (*J* = 13.1 Hz) in the place of the methylene (C-1) and chloromethine (C-2) in **6**.

The absolute stereochemistry of reticulidin A (**10**) was determined by modified Mosher's method.[7] When NMR spectra were recorded with MTPA derivatives of **10**, positive values ($\Delta\delta_{S-R}$) were observed for H-1β (+0.087), H_3-11 (+0.016), and H-9 (+0.048), while negative values were detected for H-3 (−0.021), H_3-12 (−0.008), and H_3-13 (−0.006). Therefore, the absolute configuration of **10** was determined as (2*R*,3*R*,5*S*,10*S*). Reticulidin B (**8**) did not form MTPA esters when treated with MTPA, DCC, and DMAP, presumably due to steric hindrance of the hydroxyl group. However, from the result with **10** and their close structural relationship, it could be concluded that the absolute stereochemistries of **8**−**12** and **2** and **3** are as depicted on the structures.

The aldehydes **2** and **3** could possibly be catabolic products of corresponding carbonimidic dichlorides. However, the possibility of their role as biosynthetic precursors could not be ruled out. At this point we have no conclusive evidence to determine their biosynthetic relationship. Four of the new sesquiterpenes, **1**−**4**, showed moderate cytotoxicity against P-388, A549, HT29, and MEL28 cell lines with IC_{50} values of 0.1−1 μg/mL.

Experimental Section

General Experimental Procedures. IR spectra were measured on a JASCO FT/IR 300 and UV spectra on a UVIDEC 610 spectrophotometer. NMR spectra were recorded on a JEOL A500 instrument at 500 MHz (^1H) and 125 MHz (^{13}C). LREIMS and HREIMS were obtained using a Hitachi M-2500 mass spectrometer. Optical rotation was taken on a JASCO DIP-1000 polarimeter.

Animal Material. A specimen (90 g, wet wt) of the title sponge was collected by hand using scuba at −15 m in Iriomote Island, Okinawa, in May 1998. A voucher specimen (QM G317008) is deposited at Queensland Museum, Brisbane, Australia, and the sample was identified by Dr. John N. A. Hooper, Natural Environment Program, Queensland Museum, South Brisbane, Queensland, Australia.

Extraction and Isolation. The sponge sample was kept frozen until extraction. The whole animal was extracted three times with Me_2CO (500 mL). The combined extracts were concentrated in vacuo, and the residue partitioned between EtOAc and H_2O to obtain a lipophilic extract (0.70 g). Most of the extract (0.65 g) was separated on a Si gel column by eluting stepwise with heptane, heptane−CH_2Cl_2, CH_2Cl_2, CH_2Cl_2−EtOAc, EtOAc, EtOAc−MeOH, and MeOH to give nine fractions. The first fraction (12.7 mg) was further separated by preparative TLC (SiO_2, heptane−CH_2Cl_2, 10:1) followed by HPLC (RP_{18}, MeOH−H_2O, 15:1) to give compounds **5** (2.0 mg) and **6** (1.9 mg). The second fraction (39.8 mg) was separated by HPLC (SiO_2, heptane−CH_2Cl_2, 9:1) to give compounds **1** (6.1 mg), **4** (1.6 mg), and **6** (8.0 mg). The fourth fraction (64.0 mg) was separated by HPLC (SiO_2, heptane−CH_2Cl_2, 3:1) to give **11** (1.5 mg) and **12** (1.7 mg). The fifth fraction (88.7 mg) was repeatedly separated by preparative TLC (SiO_2, first: heptane−EtOAc, 9:1; second: heptane−CH_2Cl_2, 3:2; third: CH_2Cl_2) to give **2** (1.6 mg), **3** (1.6 mg), **8** (9.1 mg), and **9** (5.8 mg). The sixth fraction (184.5 mg) was separated on a Si gel column (heptane−CH_2Cl_2−EtOAc) followed by preparative TLC (heptane−CH_2Cl_2, 3:2) to give **7** (12.0 mg) and **10** (4.6 mg).

Compound 1: colorless oil; $[\alpha]^{25}_D$ +4.5° (*c* 0.20, $CHCl_3$); UV (MeOH) λ_{max} (log ε) 205 (3.6) nm; IR (neat) ν_{max} 1655, 877 cm^{-1}; ^1H NMR ($CDCl_3$) δ 0.84 (3H, s, H_3-13), 1.16 (3H, s, H_3-12), 1.74 (1H, m, H-7a), 1.77 (1H, m, H-5), 1.81 (1H, m, H-7b), 1.86 (1H, m, H-2β), 1.91 (1H, m, H-8a), 2.04 (1H, dt, *J* = 4, 13 Hz, H-1α), 2.12 (1H, dq, *J* = 13, 4 Hz, H-2α), 2.38 (1H, m, H-8b), 2.41 (1H, m, H-1β), 3.84 (2H, d, *J* = 7 Hz, H-11), 3.90 (1H, dd, *J* = 4, 11 Hz, H-3), 4.60 (1H, t, *J* = 7 Hz, H-10), 4.66 (1H, s, H-14a), 4.95 (1H, s, H-14b), 5.07 (1H, s, H-15a), 5.19 (1H, s, H-15b); ^{13}C NMR ($CDCl_3$) δ 15.9 q (C-13), 24.3 t (C-7), 27.2 q (C-12), 30.7 t (C-8), 34.5 t (C-2), 35.4 t (C-1), 41.8 s (C-4), 52.4 d (C-5), 59.3 t (C-11), 62.2 d (C-10), 70.9 d (C-3), 109.2 t (C-14), 114.4 t (C-15), 127.0 s (C-16), 145.6 s (C-6), 146.3 s (C-9); ESIMS *m*/*z* 369 ([M^+], 62 rel %); EIMS *m*/*z* 334 ([M − Cl]$^+$, 100), 336 (98), 338 (32), 298 (65), 300 (40), 302 (7), 262 (30), 264 (12 rel %): HREIMS *m*/*z* 334.0870 (calcd for $C_{16}H_{23}{}^{35}Cl_3N$, 334.0894).

Compound 2: colorless oil, $[\alpha]^{25}_D$ +16° (*c* 0.13, $CHCl_3$), UV (MeOH) λ_{max} (log ϵ) 235 (3.5), 285 (3.3) nm; IR (neat) ν_{max} 3458, 1714, 1666 cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.11 (6H, s, H_3-12,13), 1.14 (3H, s, H_3-11), 1.38 (1H, dd, J = 3, 12 Hz, H-5), 1.52 (1H, br d, J = 14 Hz, H-1α), 1.65 (1H, dq, J = 4, 13 Hz, H-6*β*), 1.98 (1H, m, H-6α), 2.02 (2H, m, H_2-9), 2.05 (1H, m, H-7α), 2.06 (1H, dd, J = 3, 14 Hz, H-1*β*), 2.35 (1H, br s, OH), 3.50 (1H, br d, J = 14 Hz, H-7*β*), 3.94 (1H, d, J = 3 Hz, H-3), 4.18 (1H, q, J = 3 Hz, H-2), 5.78 (1H, d, J = 8 Hz, H-14), 10.02 (1H, d, J = 8 Hz, H-15); ^{13}C NMR ($CDCl_3$) δ 17.8 q (C-13), 20.8 q (C-11), 23.9 t (C-6), 29.5 t (C-7), 30.4 q (C-12), 36.7 s (C-10), 39.5 s (C-4), 45.1 t (C-1), 54.1 d (C-5), 55.8 t (C-9), 71.9 d (C-2), 76.3 d (C-3), 127.5 d (C-14), 163.5 s (C-8), 190.1 d (C-15); EIMS *m/z* 270 (M^+, 100), 272 (33), 255 (18), 226 (48), 217 (74 rel %); HREIMS *m/z* 270.1363 (calcd for $C_{15}H_{23}{}^{35}ClO_2$, 270.1384).

Compound 3: colorless oil, $[\alpha]^{25}_D$ −28° (*c* 0.13, $CHCl_3$), UV (MeOH) λ_{max} (log ϵ) 240 (3.9), 285 (3.1) nm; IR (neat) ν_{max} 3467, 1716, 1651 cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.09 (3H, s, H_3-12), 1.10 (3H, s, H_3-13), 1.16 (3H, s, H_3-11), 1.38 (1H, dd, J = 2.5, 13.0 Hz, H-5), 1.58 (1H, m, H-1α), 1.67 (1H, dq, J = 4.0, 13.0 Hz, H-6*β*), 1.80 (1H, d, J = 13.0 Hz, H-9α), 1.96 (1H, m, H-6α), 2.09 (1H, dd, J = 2.5, 14.5 Hz, H-1*β*), 2.26 (1H, dt, J = 6.0, 13.0 Hz, H-7α), 2.36 (1H, s, OH), 2.49 (1H, br d, J = 13.0 Hz, H-7*β*), 3.02 (1H, br d, J = 13.0 Hz, H-9*β*), 3.94 (1H, d, J = 3.0 Hz, H-3), 4.19 (1H, br s, H-2), 5.95 (1H, d, J = 8.1 Hz, H-14), 9.95 (1H, d, J = 8.1 Hz, H-15); ^{13}C NMR ($CDCl_3$) δ 17.8 q (C-13), 20.9 q (C-11), 24.2 t (C-6), 30.3 q (C-12), 36.5 s (C-10), 37.9 t (C-7), 39.5 s (C-4), 45.1 t (C-1), 47.2 t (C-9), 54.2 d (C-5), 71.9 d (C-2), 76.3 d (C-3), 127.7 d (C-14), 163.7 s (C-8), 190.5 d (C-15); EIMS *m/z* 270 (M^+, 98), 272 (34), 255 (42), 226 (70), 217 (100 rel %); HREIMS *m/z* 270.1400 (calcd for $C_{15}H_{23}{}^{35}ClO_2$, 270.1384).

Compound 4: colorless oil, $[\alpha]^{25}_D$ +40°(*c* 0.13, $CHCl_3$), UV (MeOH) λ_{max} (log ϵ) 288 (4.2) nm; IR (neat) ν_{max} 1640, 900 cm^{-1}; ^1H NMR ($CDCl_3$) δ 0.94 (3H, s, H_3-13), 1.03 (3H, s, H_3-11), 1.10 (3H, s, H_3-12), 1.20 (1H, dd, J = 2, 13 Hz, H-5), 1.38 (1H, dt, J = 4, 13 Hz, H-1α), 1.57 (1H, t, J = 3 Hz, H-6*β*), 1.59 (1H, t, J = 3 Hz, H-1*β*), 1.89 (1H, br dd, J = 7, 13 Hz, H-6α), 2.01 (1H, m, H-2α), 2.07 (1H, m, H-2*β*), 2.21 (1H, m, H-7α), 2.36 (1H, dd, J = 6, 17 Hz, H-7*β*), 3.75 (1H, dd, J = 5, 12 Hz, H-3), 5.59 (1H, s, H-9), 6.51 (1H, d, J = 13 Hz, H-14), 6.70 (1H, d, J = 13 Hz, H-15); ^{13}C NMR ($CDCl_3$) δ 16.6 q (C-13), 19.2 t (C-6), 20.8 q (C-11), 26.2 t (C-7), 28.9 q (C-12), 29.8 t (C-2), 36.0 s (C-10), 38.8 t (C-1), 40.0 s (C-4), 51.3 d (C-5), 72.4 d (C-3), 124.0 s (C-16), 128.9 d (C-15), 130.6 s (C-8), 137.7 d (C-14), 146.4 d (C-9); EIMS *m/z* 333 (M^+, 52), 335 (52), 337 (17), 339 (1), 298 (100), 300 (65), 302 (12), 262 (75), 264 (26), 226 (36 rel %); HREIMS *m/z* 333.0823 (calcd for $C_{16}H_{22}{}^{35}Cl_3N$, 333.0816).

Compound 5: colorless oil, ^1H NMR ($CDCl_3$) δ 1.61 (6H, s, H_3-13, 14), 1.68 (3H, s, H_3-12), 1.99 (2H, t, J = 7 Hz, H-8), 2.07 (2H, q, J = 7, 13 Hz, H-9), 2.23 (2H, m, H-5), 2.28 (2H, m, H-4), 5.09 (1H, br t, J = 7 Hz, H-10), 5.16 (1H, tq J = 7, 2 Hz, H-6), 5.19 (1H, br s, H-15a), 5.23 (1H, br s, H-15b), 6.62 (1H, d, J = 13 Hz, H-2), 6.87 (1H, d, J = 13 Hz, H-1); ^{13}C NMR ($CDCl_3$) δ 16.1 q (C-14), 17.7 q (C-13), 25.7 q (C-12), 26.6 t (C-5), 26.7 t (C-9), 32.1 t (C-4), 39.7 t (C-8), 120.3 t (C-15), 123.4 d (C-6), 124.3 d (C-10), 125.2 s (C-16), 130.8 d (C-1), 131.4 s (C-11), 135.9 s (C-7), 137.0 d (C-2), 143.9 s (C-3).

(*R*)-MTPA Ester of 10. A mixture of 0.35 mg of reticulidin A (**10**), 0.31 mg of DCC, 0.35 mg of (*R*)-MTPA, and 0.12 mg of DMAP in 0.15 mL of CH_2Cl_2 was kept standing at room temperature for 3 h. After removal of the solvent, the residue was separated by preparative-TLC (SiO_2, hexane−EtOAc, 4:1) to afford 0.30 mg of (*R*)-MTPA ester: ^1H NMR ($CDCl_3$) δ 1.034 (3H, s, H_3-13), 1.156 (6H, s, H_3-11, 12), 2.025 (1H, dd, J = 4, 12 Hz, H-1*β*), 3.741 (1H, d, J = 11 Hz, H-3), 5.387 (1H, dt, J = 5, 11 Hz, H-2), 5.562 (1H, s, H-9), 6.486 (1H, d, J = 13 Hz, H-14), 6.712 (1H, d, J = 13 Hz, H-15).

(*S*)-MTPA Ester of 10. The ester was similarly prepared as above using (*S*)-MTPA: ^1H NMR ($CDCl_3$) δ 1.028 (3H, s, H_3-13), 1.148 (3H, s, H_3-12), 1.172 (3H, s, H_3-11), 2.112 (1H, dd, J = 4, 12 Hz, H-1*β*), 3.720 (1H, d, J = 11 Hz, H-3), 5.417 (1H, dt, J = 5, 11 Hz, H-2), 5.610 (1H, s, H-9), 6.507 (1H, d, J = 13 Hz, H-14), 6.729 (1H, d, J = 13 Hz, H-15).

Treatment of Reticulidin B (8) with an Acid. A mixture of 1.0 mg of reticulidin B (**8**) and a catalytic amount of *p*-toluenesulfonic acid monohydrate in 0.5 mL of 30% aqueous THF was kept standing at room temperature for 12 h. The reaction mixture showed only one spot on TLC (SiO_2, heptane−EtOAc, 3:2), and unreacted **8** (0.8 mg) was recovered.

Cytotoxicity Assay. The bioassay was conducted by Dr. D. G. Gravalos, PharmaMar, Madrid, Spain, using P-388, A549, HT29, and MEL28 cell lines.

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