147.3, 141.5, 127.1, 125.7, 122.6, 110.8, 108.8, 108.6, 64.3, 64.00, 64.07, 47.3, 43.7, 39.5, 35.6, 33.6, 31.3, 30.9, 26.1, 26.0, 22.5, 18.5; MS 374 (M^+, 10), 99 ($C_5H_7O_2$, 100). Anal. Calcd for $C_{23}H_{34}O_4$: C, 73.75; H, 9.17. Found: C, 73.82; H, 9.22.

1-(4,4-(Ethylenedioxy)-2-(2-hydroxyethyl)-2-methyl-cyclohexyl)-3-(5,5-(ethylenedioxy)-2-methylcyclo-hexenyl)-1-propanol (15). Thexylborane–methyl sulfide complex (0.15 mmol) was prepared by adding borane–methyl sulfide complex (14.6 µL, 0.15 mmol) to 2,3-dimethyl-2-butene (0.02 mL, 0.15 mmol) in $DCCl_3$ (1 mL) at 0 °C. The resulting solution was stirred for 3 h and added dropwise to triene 11 (50 mg, 0.13 mmol) in $DCCl_3$ (0.5 mL) at -78 °C. The reaction mixture was allowed to warm gradually to room temperature, stirred 24 h, and quenched with absolute ethanol (1 mL). Crushed NaOH (32 mg, 0.80 mmol) was added, and the reaction mixture was cooled to 0 °C; 30% H_2O_2 (0.07 mL, 0.067 mmol) was added dropwise, and the oxidation mixture was stirred for 8 h at room temperature and for 3 h at 50 °C. After being cooled to room temperature and saturated with NaCl, the aqueous phase was washed three times with CH_2Cl_2, and the combined organic extracts were dried over $MgSO_4$. Removal of the solvent under reduced pressure afforded 0.326 g of a yellow oil. Column chromatography on neutral activity III alumina (10% ethanol in ethyl acetate) afforded diol 15 (8.1 mg, 15%): IR (film) ν 3380, 2920; ¹H NMR (300 MHz) δ 3.95–3.75 (m, 8 H, OCH_2CH_2O), 3.75–3.52 (m, 3 H, CH_2OH), 2.18–0.74 [env, 27 H, s at 1.65 (=CCH₃) and 1.00 (CCH₃), CH₂, CH]; MS (direct probe) 410 (M^+, 32), 168 (B).
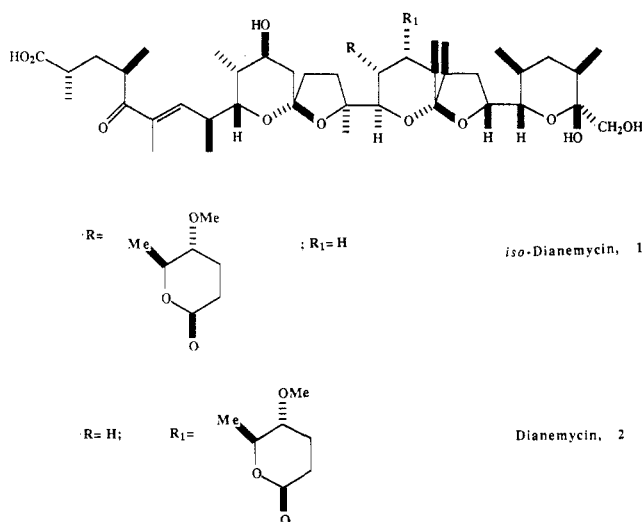
Structure Elucidation of a New Polyether Antibiotic iso-Dianemycin

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In the course of screening soil samples for new antibacterial agents,[1] we isolated a new polyether natural product (1) related to Dianemycin (2).[2] Herein, we describe the detailed structure of iso-Dianemycin (1) via NMR and high-resolution mass spectroscopic analyses, as well as solid-state techniques.

The structure elucidation of 1 was initiated by assigning a molecular formula. NMR analysis via the polarization
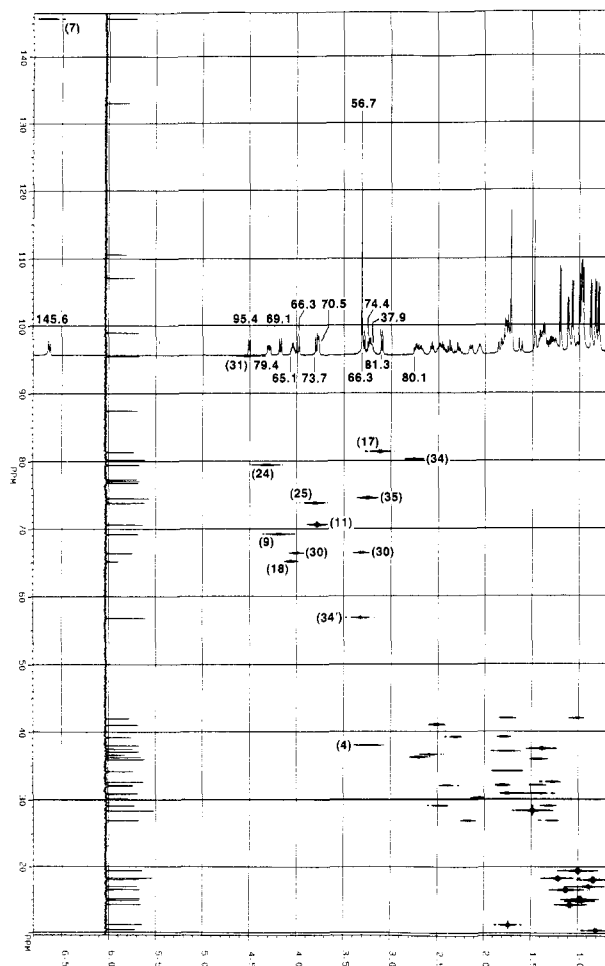
Figure 1. ¹³C–¹H correlation spectrum of polyether 1. The numbers in parentheses refer to the carbon numbering system, whereas the numbers appearing on the ¹H NMR spectrum are the actual chemical shifts of the correlated carbon resonances.

transfer (DEPT)[3] experiment supported a carbon number of 47 with 74 nonexchangeable protons directly bonded to carbon (see Table I). Furthermore, the number of exchangeable protons, and their corresponding vicinally attached carbons, was ascertained by the direct observation of vicinal deuterium isotope shifts for four carbon resonances;[4] namely, carbons 1, 11, 29, and 30 (see the figures for the numbering scheme) exhibiting chemical shifts of 183.8, 70.5, 98.8, and 66.3 ppm, respectively. Thus, the total number of protons was 78. The assignment of the molecular formula was completed by mass spectral experiments, since a molecular ion for the rubidium salt of 1 (M^+ – Rb = m/e 951.5779) was observed in the high-resolution FAB mass spectrum. Since the carbon and proton numbers were defined, the only heteroatom that permitted a reasonable fit of the high-resolution data was oxygen, which defined the molecular formula as $C_{47}H_{78}O_{14}$.

Support for the definition of oxygen as the only heteroatom was also derived from an assessment of the carbon functionality (Table I includes the carbon functionality), which was assigned by chemical shift analogy.[5] A total of 17 carbons (see Table I) contained oxygen as a sub-

(1) The fermentation and isolation of 1, as well as the characterization of the producing organism, will appear elsewhere.

(2) Mizoue, K.; Seto, H.; Mizutani, T.; Yamagishi, M.; Kawashima, A.; Omura, S.; Ozeki, M.; Otake, M. J. Antibiot. 1980, 33, 144.

(3) Doddrell, D.; et al. J. Magn. Reson. 1982, 48, 323.

(4) Hauske, J.; DiBrino, J.; Guadliana, M.; Kostek, G. J. Org. Chem. 1986, 51, 2808.

(5) Seto, H.; Otake, N. In Polyether Antibiotics. Naturally Occurring Ionophores; Westley, J. W., Ed.; Marcel Dekker: New York, 1983; Vol. 2, p 335.

Table I. NMR Spectral Data of Polyether 1

C no.	chem shift	mult	fragmnt designtn	functionality	C no.	chem shift	mult	fragmnt designtn	functionality
5	205.8	Q	1	ketone carbonyl of enone	27	37.3	CH_2	2	alkyl[a]
1	183.8	Q	1	carboxylate	10	36.9	CH	1	alkyl[a]
7	145.6	CH	1	olefin of enone	22	36.4	CH	2	alkyl[a]
6	133.0	Q	1	olefin of enone	8	36.1	CH	1	alkyl[a]
21	110.5	Q	2	ketal	28	35.7	CH	2	alkyl[a]
13	107.0	Q	1	ketal	12	34.0	CH_2	1	alkyl[a]
29	98.8	Q	2	hemiketal	26	32.4	CH	2	alkyl[a]
31	95.4	CH	3	anomeric acetal	19	31.9	CH_2	2	alkyl[a]
16	87.4	Q	1	ether	15	31.8	CH_2	1	alkyl[a]
17	81.3	CH	2	ether	32	30.7	CH_2	3	alkyl[a]
34	80.1	CH	3	ether	20	30.0	CH	2	alkyl[a]
24	79.4	CH	2	ether	23	29.0	CH_2	2	alkyl[a]
35	74.4	CH	3	ether	16′	28.3	CH_3	1	alkyl[a]
25	73.7	CH	2	ether	33	26.8	CH_2	3	alkyl[a]
11	70.5	CH	1	carbinol	2′	19.3	CH_3	1	alkyl[a]
9	69.1	CH	1	ether	35′	18.2	CH_3	3	alkyl[a]
30	66.3	CH_2	2	carbinol	26′	17.9	CH_3	2	alkyl[a]
18	65.1	CH	2	ether	28′	16.9	CH_3	2	alkyl[a]
34′	56.7	CH_3	3	ether	8′	16.4	CH_3	1	alkyl[a]
3	41.9	CH_2	1	alkyl[a]	22′	15.0	CH_3	2	alkyl[a]
2	40.9	CH	1	alkyl[a]	20′	14.7	CH_3	2	alkyl[a]
14	39.1	CH_2	1	alkyl[a]	4′	14.1	CH_3	1	alkyl[a]
4	37.9	CH	1	alkyl[a]	6′	11.1	CH_3	1	alkyl[a]
					10′	10.3	CH_3	1	alkyl[a]

[a] No heteroatom substitution.

Figure 2. $^{13}C-^{1}H$ correlation spectrum of polyether 1 in the range 80–10 ppm, where the numbers in parentheses refer to the carbon numbering system and the numbers appearing on the ^{1}H NMR spectrum are the actual chemical shifts of the correlated carbon resonances.

Figure 3. COSY spectrum of polyether 1 detailing the correlation of fragment 1. The numbers in parentheses refer to the carbon numbering system, whereas the numbers appearing on the ^{1}H NMR spectrum are the actual chemical shifts of the correlated carbon resonances. The numbers appearing on the two-dimensional plot define the COSY connectivity.

Figure 4. Expansion of Figure 3 in the range 0.8–2.8 ppm.

Figure 5. COSY spectrum of polyether 1 detailing the correlation of fragment 2. The numbers in parentheses refer to the carbon numbering system, whereas the numbers appearing on the ^{1}H NMR spectrum are the actual chemical shifts of the correlated carbon resonances. The numbers appearing on the two-dimensional plot define the COSY connectivity.

stituent. The carbon resonances at 205.8 ppm (ketone) and 183.8 ppm (carboxylate) were the only sp^2-hybridized centers bearing heteroatoms. Furthermore, the remaining heteroatom-substituted carbon centers were all sp^3-hybridized and were comprised of two ketals (110.5 and 107.0 ppm), one hemiketal (98.8 ppm), one anomeric acetal (95.4 ppm), nine ethers (87.4, 81.3, 80.1, 79.4, 74.4, 73.7, 69.1, 65.1, and 56.7 ppm), and two carbinols (70.5 and 66.3 ppm).

With the molecular formula and carbon functionality of 1 defined, the structure problem required a definition of carbon connectivities. In this regard, mass spectral data proved invaluable, since it reduced the structure elucidation of a rather large, structurally complex molecule to more manageable substructures. Mass spectral experiments not only yielded a molecular ion, but also provided some very useful structure fragments. Specifically, the FAB mass spectrum defined one structure element derived from the molecular ion, namely, $C_{40}H_{64}O_{11}$ (m/e 721.0211), whereas the EI mass spectrum defined three notable structure fragments [fragment 1 ($C_{22}H_{34}O_6$, m/e 394.2362), fragment 2 ($C_{18}H_{29}O_5$, m/e 325.2014) and fragment 3 ($C_7H_{13}O_2$, m/e 129.0923)]. It appears that fragment 3 defines the relationship between the two FAB produced ions, however, there is an oxygen deficiency. Since carbohydrates frequently fragment via an α-cleavage as well as a β-cleavage pathway,[6] it seems reasonable to assign fragment 3 as a carbohydrate residue which fragments via
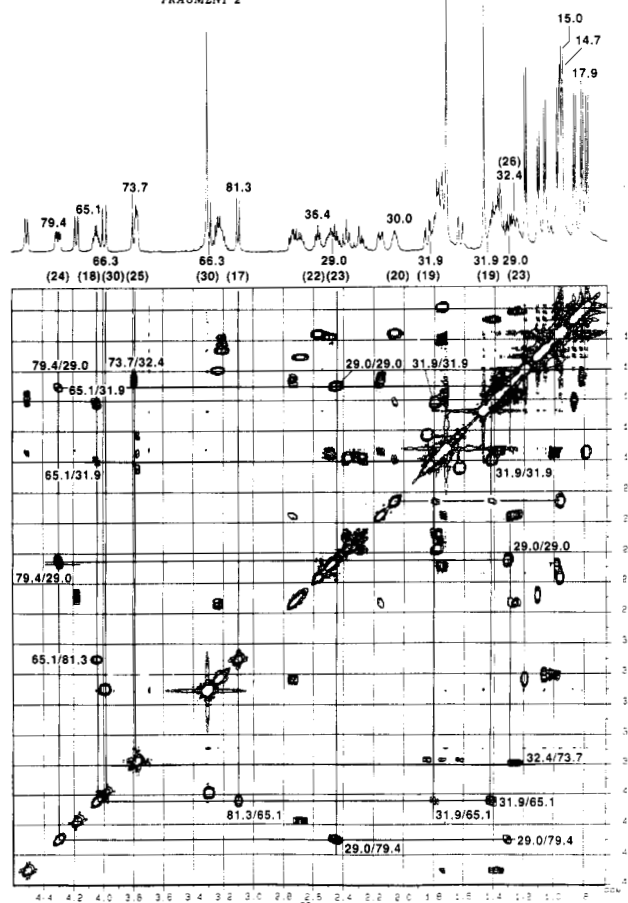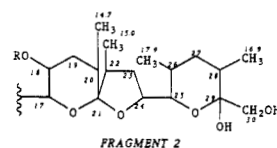
an α-cleavage in the EI spectrum and a β-cleavage in the FAB spectrum. Furthermore, fragment 1 and fragment 2 appear to define the structure element ($C_{40}H_{64}O_{11}$), which is observed in the FAB mass spectrum. Thus, an assessment of the mass spectral data reduced the structure problem to an assignment of structure fragments 1, 2, and 3.

The carbon connectivities of each of the proposed fragments were determined by two-dimensional NMR techniques via a two step procedure: (1) the C–H connectivities were assigned by two-dimensional heteronuclear ^{13}C–^{1}H correlation spectroscopy[7] (see Figures 1 and 2); (2) the carbon–carbon connectivities were derived from the assignment of the vicinally coupled protons via two-dimensional homonuclear ^{1}H–^{1}H (COSY) correlations[8] (Figures 3–8). For example, the COSY spectrum (Figures 3 and 4) defines the carbon network for fragment 1 as C_2–C_4 (40.9, 41.9, and 37.9 ppm), C_7–C_{12} (145.6, 36.1, 69.1, 36.9, 70.5, and 34.0 ppm), and C_{14}–C_{15} (39.1 and 31.8 ppm).

(6) Occolowitz, J. L.; Hamill, R. L. In *Polyether Antibiotics. Naturally Occurring Ionophores*; Westley, J. W., Ed.; Marcel Dekker: New York, 1983; Vol. 2, p 197.

(7) Bendall, M.; Pegg, D.; Doddrell, D.; Thomas, D. *J. Magn. Reson.* **1982**, *46*, 43.

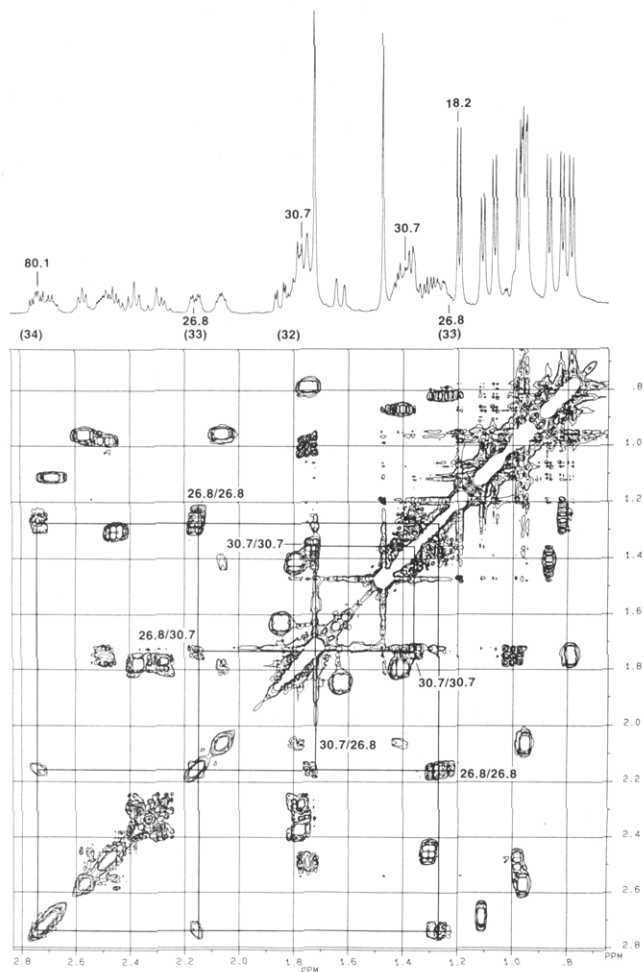(8) Wagner, G.; Kumai, A.; Wuthrich, K. *Eur. J. Biochem.* **1981**, *114*, 375.

Figure 6. Expansion of Figure 5 in the range 0.8–2.8 ppm.

Figure 7. COSY spectrum of polyether 1 detailing the correlation of fragment 3. The numbers in parentheses refer to the carbon numbering system, whereas the numbers appearing on the ^{1}H NMR spectrum are the actual chemical shifts of the correlated carbon resonances. The numbers appearing on the two-dimensional plot define the COSY connectivity.

The methyl substituents corresponding to carbon positions 2, 4, 8, and 10 are readily defined in the COSY spectrum (19.3, 14.1, 16.4, and 10.3 ppm, respectively, Figure 4). Although the methyl groups on quaternary carbon centers 6 and 16 (11.1 and 28.3 ppm) were initially assigned by chemical shift analogy,[9] confirmation of the assignment was accomplished by relay COSY experiments.[10] In analogous fashion the carbon networks for fragments 2 and 3 were readily defined. The COSY spectrum (Figures 5 and 6) defines the carbon network of fragment 2 as C_{17}–C_{20} (81.3, 65.1, 31.9, and 30.0 ppm) and C_{22}–C_{28} (36.4, 29.0, 79.4, 73.7, 32.4, 37.3, and 35.7 ppm). The methyl substituents corresponding to carbon positions 20, 22, 26, and 28 are also readily defined in the COSY spectrum (14.7, 15.0, 17.9, and 16.9 ppm, respectively, Figure 6). Figure 7 details the assignment of fragment 3 as the 4′-O-methyl amicetose,[5] which is consistent with the mass spectral observations. The assignment of the β-configuration for the carbohydrate derives from chemical shift analogy, since it is well known that the chemical shift of the anomeric center is very sensitive to its structural environment.[9]

The assignment of the position of the carbohydrate moiety at C-18 is based upon consideration of the deuterium isotope shift experiment, which defined the C-18 (65.1 ppm) position as the only remaining ethereal carbon in either fragment 1 or fragment 2. Support for this assignment derives from NOE experiments.[11] For example, irradiation of the ^{1}H NMR band absorbing at δ 4.50

[correlates to C_{31} (94.5 ppm)] resulted in an approximately 8–10% nuclear Overhauser enhancement for the ^{1}H NMR band absorbing at δ 4.05 [correlates to C_{18} (65.1 ppm)]. Since the PMR resonance at δ 4.50 is the anomeric proton of fragment 3 and the band absorbing at δ 4.05 is the methinyl proton of the C_{18} position of fragment 2, the carbohydrate moiety must be substituted at C_{18} in fragment 2.

All that remains to complete the carbon network is to assign the position of the quaternary centers within fragment 1 (carbons 5, 13, and 16) and fragment 2 (carbons 21 and 29) and, finally, unite the fragments. Fortunately, this aspect of the structural problem is readily solved via relayed COSY experiments.[10] Thus, carbons 5, 13, and 16 in fragment 1 absorb at 205.8, 107.0, and 87.4 ppm, respectively, whereas carbons 21 and 29 in fragment 2 absorb at 110.5 and 98.8 ppm, respectively (see Table I).

The absolute stereochemistry of compound 1 was established by solid state analysis of the rubidium salt of 1. A computer generated rendering of 1 (Figure 9) clearly supports the NMR and mass spectral analyses.[13]

(9) Seto, H.; et al. *Tetrahedron Lett.* **1987**, *28*, 3357.
(10) Eich, G.; Bodenhausen, G.; Ernst, R. R. *J. Am. Chem. Soc.* **1982**, *104*, 3731.

(11) Noggle, J.; Schirmer, R. *The Nuclear Overhauser Effect*; Academic Press: New York, 1971.

Figure 8. Expansion of Figure 7 in the range 0.8–2.8 ppm.

Figure 9. The computer rendering of the solid-state structure of polyether **1**.

anomalous dispersion of the Rb ion. The refined structure was plotted using the SHELXTL[12] plotting package (Figure 9).

Acknowledgment. We thank R. Ware and J. Stroh for obtaining mass spectral data and D. Rescek for obtaining NMR data. The X-ray data were obtained by J. Bordner.

Supplementary Material Available: Tables containing coordinates, anisotropic temperature factors, bond distances, and torsional angles for Figure 9 (9 pages). Ordering information is given on any current masthead page.

Experimental Section

Structural assignments were derived from a variety of one-dimensional and two-dimensional (COSY and heteronuclear ^{1}H–^{13}C correlated) NMR experiments carried out on a Bruker (^{1}H NMR, 250 MHz; ^{13}C NMR, 62.8 MHz) WH-250 spectrometer operating at ambient temperatures. The carbon type (methine, methylene, methyl, or quaternary) was determined by DEPT experiments. High-resolution electron impact mass spectra were obtained on an AEI-MS 30 spectrometer and FAB mass spectra were obtained on a VG 70/250 spectrometer. The three-dimensional structure of the Rubidium salt of 1 (crystallized from CH$_3$OH) was determined by X-ray crystallography with a crystal that measured 0.22 × 0.25 × 0.28 mm. A 1-Å data set (maximum sin θ/λ = 0.5) was collected on a Nicolet R3m/μ diffractometer, and a trial structure was obtained by direct methods revealing the following lattice parameters: a = 12.384 (3) Å, b = 16.328 (4) Å, and c = 14.190 (5) Å with α = 90.0°, β = 98.84 (2)°, and γ = 90.0°. The space group was determined to be $P2_1$ with two molecules per unit cell. The molecular formula was C$_{47}$H$_{77}$O$_{14}$·Rb·2CH$_3$OH with a calculated density of 1.19 g/cm^3. There were 3054 reflections collected, and of those reflections 2848 (93%) with $I > 3.0\sigma$ were adjudged observed. This trial structure refined routinely. Hydrogen positions were calculated whenever possible. The methyl hydrogens and the hydrogens on oxygen were located by difference Fourier techniques. The shifts calculated in the final cycle of least-squares refinement were all less than 0.1 of their corresponding standard deviations. The final R index was 0.059. The absolute configuration was determined by using the

New Synthesis from β-Pinene of Tetracyclo[6.2.1.0^{1,6}.0^{6,10}]undecanes, an Unusual Ring System

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The product (**2**) of the ene reaction between β-pinene (**1**) and acryloyl chloride cyclizes on heating at 150 °C in tributylamine to 10,10-dimethyltricyclo[7.1.1.0^{2,7}]undec-2(7)-en-6-one (**3**), 10-chloro-9,9-dimethyltricyclo[6.2.1.0^{1,6}]undecan-5-one (**4**) of unstated stereochemistry, a number of ring-opened hydrogenated naphthalenes, and unidentified substances.[1,2] We now establish the stereochemistry of the chloro ketone (**4**), show that one of the unidentified substances is 9,9-dimethyltetracyclo[6.2.1.0^{1,6}.0^{6,10}]undecan-2-one (**5**), and describe the preparation of this new representative of an unusual ring system from the chloro ketone (**4**).

The ene reaction between (−)-β-pinene (**1**) and acryloyl chloride, followed by treatment of the crude product (**2**) with tributylamine, was carried out as described by Wolinsky et al.,[2] and products **3** and **4** were purified by chromatography in hexane–ether mixtures on silica gel. Further elution from this column after elution of the tricyclic ketone (**3**) yielded a new, optically active, ketone,

(12) Sheldrick, G. M. SHELXTL user manual; Nicolet Instrument Co., 1981.

(13) The structure of the related 19-deoxy aglycon also has been reported; see: Westley, J. W.; et al. *J. Antibiot.* **1984**, *37*, 813.
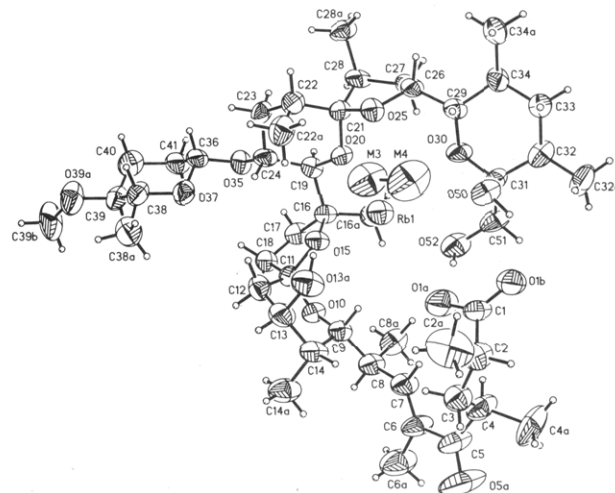
(1) (a) Krieger, H.; Yrjanheikki, E.; Huhtala, P. *Finn. Chem. Lett.* **1978**, 219. (b) Krieger, H.; Huhtala, P.; Tanninen, N. *Finn. Chem. Lett.* **1984**, *2*, 29. (c) For examples of catalyzed ene reactions of β-pinene, see: Snider, B. B. *J. Org. Chem.* **1974**, *39*, 255.

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