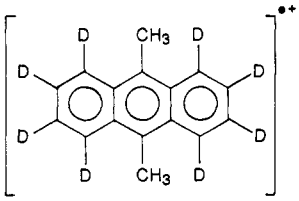
3. $SbPh_3$ + 1,1,2,2-Tetrachloroethane System. The reaction of $SbPh_3$ (0.05 M) and 1,1,2,2-tetrachloroethane in the presence of aluminum chloride resulted in an EPR spectrum (Figure S6a[12]) identical with that of the dibenzo[*a*,*c*]triphenylene radical cation in $SbCl_5$–CH_2Cl_2 solution.[16] Proton hyperfine coupling constants of 0.60, 2.00, 2.27, and <0.03 G (Table S1[12]) were used to simulate the spectrum (Figure S6b[12]).

This radical cation occurs by first the formation of 1,1,2,2-tetraphenylethane upon reaction of $SbPh_3$ with the alkyl carbonium ion. Formation of dibenzo[*a*,*c*]triphenylene occurs via the well-known Scholl condensation for 1,1,2,2-tetraphenylethane. If 1,1,2,2-tetrachloroethane is replaced by 1,1,2,2-tetrabromomethane, an identical spectrum is observed. This same spectrum is also observed when benzene reacts with 1,1,2,2-tetrachloro- or 1,1,2,2-tetrabromomethane in excess $AlCl_3$.

4. $SbPh_3$ + 1,1-Dichloroethane System. The ESR spectrum (Figure S7[12]) observed in the reaction of $SbPh_3$ (0.05 M) with 1,1-dichloroethanes, under the influence of $AlCl_3$, is identical with that of the 9,10-dimethylanthracene radical cations in the molten $SbCl_3$.[17] Proton hyperfine coupling constants of a_H = 2.52, a_H = 1.20, and a_{CH_3} = 7.98 G (Table S1[12]) were used to simulate the spectrum in (Figure S7b[12]).

The EPR spectrum and coupling constants of the 9,10-dimethyl-1,2,3,4,5,6,7,8-octadeuterioanthracene radical cation is unreported in the literature. In this work, we found that the precursor molecule can be synthesized by the Friedel–Crafts alkylating reaction. Figure 1 shows the EPR spectrum of paramagnetic species formed in the reaction of the benzene-d_6 with 1,1-dichloroethane. We note that this pattern consists of seven equally spaced lines, with relative intensities 1:6:15:20:15:6:1, and that the separation between any two adjacent lines gives the value of 8.00 G, fairly close to methyl proton coupling constant in the nondeuteriated 9,10-dimethylanthracene radical cation. Each of these seven lines is split into a further multiplet line due to interaction with other magnetic nuclei. We assigned this EPR spectrum to the radical cation as shown below. The hyperfine coupling constants



were assigned by comparing the experimental spectrum with those simulated by a computer. The observed hyperfine coupling constants are listed in Table S1 (see the supplementary material).

Summary

Careful control of $SbPh_3$ concentration enables resolved EPR spectra that can be analyzed in a straightforward manner. This suggests that more complex EPR patterns may be simplified if the concentration of the reactants are carefully considered. This method may also permit various new deuteriated radical cations to be studied.

Acknowledgment. This study was partially supported by a grant from the School of Mines and Energy Development at the University of Alabama, and we acknowledge useful discussions with M. Cava.

Registry No. CH_2Cl_2, 75-09-2; $CHCl_3$, 67-66-3; $CDCl_3$, 865-49-6; $SbPh_3$, 603-36-1; 1,1,2,2-tetrachloroethane, 79-34-5; 1,1-dichloroethane, 75-34-3; anthracene cation radical, 34512-28-2; 9,10-dideuterioanthracene cation radical, 117178-97-9; dibenzo[*a*,*c*]triphenylene radical cation, 34478-92-7; 9,10-dimethylanthracene radical cation, 34526-95-9; 9,10-dimethyl-1,2,3,4,5,6,7,8-octadeuterioanthracene radical cation, 117095-79-1; 1,1,2,2-tetrabromoethane, 79-27-6.

Supplementary Material Available: EPR spectra and hyperfine coupling constants (Figures S1–S7 and Table S1) (8 pages). Ordering information is given on any current masthead page.

(16) Lewis, I. C., Singer, L. S. *J. Chem. Phys.* **1965**, *43*, 2712.
(17) Buchanan, A. C. III; Livingston, R.; Dworkin, A. S.; Smith, G. P. *J. Phys. Chem.* **1980**, *84*, 423.

Boron Trifluoride Mediated Reaction of 1,9-Dihalopentacyclo[5.4.0.0^{2,6}.0^{3,10}.0^{5,9}]undecane-8,11-diones with Ethyl Diazoacetate: A Novel Synthetic Entry into the Cyclopent[*a*]indene Ring System

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Received July 11, 1988

As part of a program that is concerned with the synthesis and chemistry of substituted pentacyclo[5.4.0.0^{2,6}.0^{3,10}.0^{5,9}]undecanes (PCUD),[1] we have recently undertaken a study of the Lewis acid promoted reaction of substituted PCUD-8,11-diones with ethyl diazoacetate (EDA).[2,3] Thus, reaction of 1-substituted PCUD-8,11-diones (**1**) with EDA (1 equiv) in the presence of boron trifluoride etherate has been shown to afford the corresponding monohomologation product (**2** or **3**, Scheme I). We now report the results of a study of the corresponding reactions of 1,9-dibromo- and 1,9-dichloro-PCUD-8,11-diones (**4** and **5**, respectively) with EDA (1 equiv)–$F_3B{\cdot}OEt_2$.

It has been shown that, when α-halo ketones are employed as substrates in the homolgation reaction with EDA–$F_3B{\cdot}OEt_2$, the presence of the halogen atom effectively suppresses migration of the terminus to which it is attached.[4] Since **4** and **5** contain two α-halo ketone moieties, it was of interest to determine which carbonyl group would prove to be the preferred reaction site. It was anticipated that the presence of the halogen atom adjacent to the reaction site would lead to regiospecific ketone homologation by EDA–$F_3B{\cdot}OEt_2$.[4]

In our hands, the reaction of **4** with EDA (excess) in the presence of $F_3B{\cdot}OEt_2$ afforded a single product, **6**, in 42% yield. The proton and carbon-13 NMR spectra of **6** indicated the presence of an aromatic ring (see the Exper-

(1) See: Marchand, A. P. In *Advances in Theoretically Interesting Molecules*; Thummel, R. P., Ed.; JAI: Greenwich, CT; Vol. 1, in press, and references cited therein.
(2) Marchand, A. P.; Arney, B. E., Jr.; Gilardi, R.; Flippen-Anderson, J. L. *J. Org. Chem.* **1987**, *52*, 3455.
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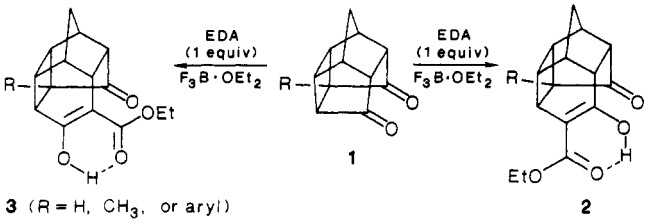
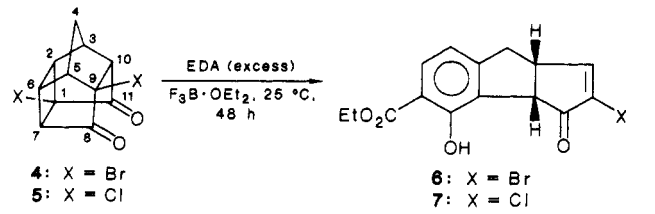
(4) (a) Dave, V.; Warnhoff, E. W. *J. Org. Chem.* **1977**, *42*, 466. (b) For a review of one carbon ring expansions of bridged bicyclic and polycyclic ketones, see: Krow, G. R. *Tetrahedron* **1987**, *43*, 3.

0022-3263/88/1953-5969$01.50/0

Scheme I



Scheme II



imental Section). The structure of **6** was established unequivocally via single-crystal X-ray structural analysis (see the Experimental Section and supplementary material). The corresponding reaction of **5** with excess EDA–$F_3B \cdot OEt_2$ led to the formation of an analogous chlorine-containing product, **7**, in 40% yield (Scheme II).

A mechanism that accounts for the exclusive formation of **6** and **7** in these reactions from **4** and **5**, respectively, is shown in Scheme III. Some key features of this mechanism merit comment: (i) In order to account for the fact that **6** and **7** are the exclusive reaction products, we suggest that preferential attack by EDA occurs at the C(8) rather than the C(11) carbonyl group. This reaction regiospecificity very likely reflects the increased degree of steric hindrance that the C(1)–Br bond presents toward nucleophilic attack at the C(11) carbonyl as compared with the corresponding steric environment which the C(9)–Br bond imposes upon the C(8) carbonyl group. (ii) Nucleophilic attack by EDA at the C(11) carbonyl group is then followed by preferential migration of the C(7)–C(8) bond in intermediate **8**.[4] (iii) Lewis acid promoted ring opening of the resulting intermediate monohomologation product, **9**, can then occur, thereby affording the observed reaction products. A control experiment has established that the cyclobutane ring in **4** does not undergo [2 + 2] cycloreversion in the presence of boron trifluoride etherate at room temperature.[5] Hence, a stepwise mechanism must be written to account for the [2 + 2] cycloreversion that follows the postulated formation of **9**.

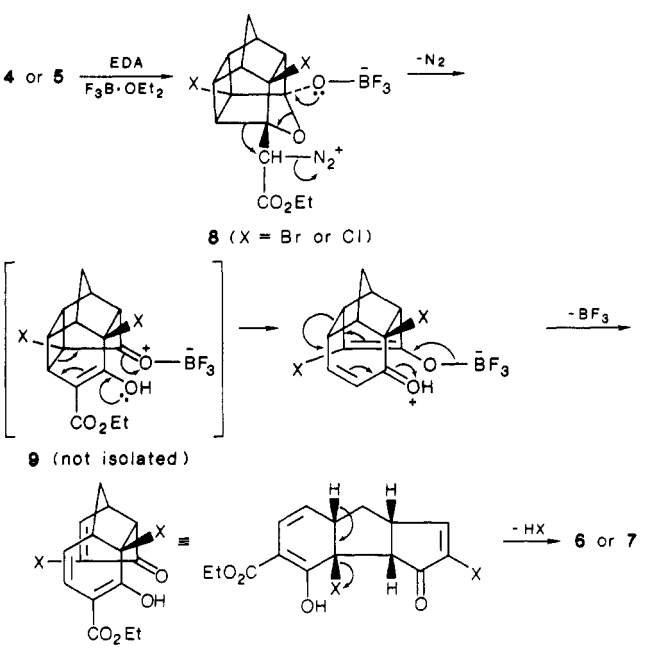
Finally, it should be noted that the rearrangements reported herein represent a useful synthetic entry into the cyclopent[*a*]indene system in one step from readily available pentacyclic cage dione precursors (**4** and **5**).

Experimental Section

Melting points are uncorrected. Substrates **4** and **5** were prepared by using the procedure described by Mehta and coworkers.[6]

Reaction of 4 with EDA–$F_3B \cdot OEt_2$. A solution of **4** (664 mg, 2.0 mmol) in anhydrous diethyl ether (150 mL) under argon was cooled to −15 °C via application of an external dry ice–carbon tetrachloride cold bath. To this stirred, cooled solution was added boron trifluoride etherate (572 mg, 4.0 mmol). To the resulting

Scheme III



solution was added ethyl diazoacetate (456 mg, 4.0 mmol), and the reaction mixture was stirred at −15 °C for 1 h. The cold bath was removed, and the stirred reaction mixture was allowed to warm slowly to room temperature. The reaction mixture was stirred at room temperature for 24 h, at which time ethyl diazoacetate (456 mg, 4.0 mmol) was added, and the reaction mixture was stirred at room temperature for 24 h. The mixture then was poured into 10% aqueous sodium bicarbonate solution (100 mL) to quench the reaction, and the layers were separated. The organic layer was washed sequentially with 10% aqueous sodium bicarbonate solution (2 × 50 mL) and with water (2 × 75 mL). The organic layer was dried (anhydrous sodium sulfate) and filtered, and the filtrate was concentrated in vacuo. The residue was purified via column chromatography (silica gel stationary phase, 15% ethyl acetate–hexane mixed solvent as eluent). Pure **6** (283 mg, 42%) was thereby obtained as colorless needles: mp 171–172 °C; IR (KBr) 3115 (w), 3040 (w), 2973 (w), 2900 (w), 1700 (s), 1650 (s), 1605 (m), 1575 (m), 1363 (s), 1315 (s), 1267 (s), 1237 (s), 1192 (m), 1161 (s), 1145 (s), 1033 (s), 1014 (m), 774 (s), 738 cm^{-1} (m); ^1H NMR ($CDCl_3$) δ 1.37 (t, J = 7.3 Hz, 3 H), 2.93 (dd, J_1 = 17.8 Hz, J_2 = 3.3 Hz, 1 H), 3.3 (dd, J_1 = 17.8 Hz, J_2 = 10.7 Hz, 1 H), 3.73–3.84 (m, 1 H), 4.27 (d, J = 6.1 Hz, 1 H), 4.34 (q, J = 7.3 Hz, 2 H), 6.68 (d, J = 8.2 Hz, 1 H), 7.65 (d, J = 3.1 Hz, 1 H), 7.72 (d, J = 8.2 Hz, 1 H), 11.2 (s, 1 H); ^{13}C NMR ($CDCl_3$) δ 14.92 (q), 36.29 (t), 43.86 (d), 53.06 (d), 61.43 (t), 111.59 (s), 115.79 (d), 125.11 (s), 125.35 (s), 130.78 (d), 150.79 (s), 159.66 (s), 162.03 (d), 170.05 (s), 197.89 (s). Anal. Calcd for $C_{15}H_{13}BrO_4$: C, 53.43; H, 3.89. Found: C, 53.50; H, 3.82.

Reaction of 5 with EDA–$F_3B \cdot OEt_2$. A solution of **5** (486 mg, 2.0 mmol) in anhydrous diethyl ether (150 mL) under argon was cooled to −15 °C via application of an external dry ice–carbon tetrachloride cold bath. To this stirred, cooled solution was added boron trifluoride etherate (572 mg, 4.0 mmol). The resulting solution was reacted with ethyl diazoacetate in the manner described above for the corresponding reaction of **4**. At the conclusion of the reaction, the reaction mixture was quenched, and the product was isolated and purified by using the method described above. Pure **7** (234 mg, 40%) was thereby obtained as colorless needles: mp 191.5–192.5 °C; IR (KBr) 3105 (w), 3050 (w), 2977 (w), 2905 (w), 1705 (s), 1650 (s), 1607 (m), 1583 (m), 1365 (s), 1318 (s), 1272 (s), 1238 (s), 1195 (m), 1163 (s), 1147 (s), 1034 (s), 1015 (m), 961 (w), 776 (s), 746 (m); ^1H NMR ($CDCl_3$) δ 1.36 (t, J = 7.3 Hz, 3 H), 2.94 (dd, J_1 = 18.2 Hz, J_2 = 3.4 Hz, 1 H), 3.31 (dd, J_1 = 18.2 Hz, J_2 = 10.4 Hz, 1 H), 3.74–3.84 (m, 1 H), 4.30 (d, J = 6.2 Hz, 1 H), 4.36 (q, J = 7.3 Hz, 2 H), 6.67 (d, J = 8.2 Hz, 1 H), 7.47 (d, J = 3.1 Hz, 1 H), 7.73 (d, J = 8.2 Hz, 1 H), 11.2 (s, 1 H); ^{13}C NMR ($CDCl_3$) δ 14.19 (q), 36.43 (t), 41.73 (d), 53.62 (d), 61.44 (t), 111.61 (s), 115.79 (d), 125.09 (s), 130.80 (d),

(5) The cyclobutane ring in 1-methoxypentacyclo[5.4.0.0^{2,6}.0^{3,10}.0^{5,9}]-undecane-8,11-dione has been reported to undergo boron trifluoride promoted [2 + 2] cycloreversion smoothly at room temperature. See: Mehta, G.; Reddy, D. S.; Reddy, A. V. *Tetrahedron Lett.* **1983**, *24*, 5645.

(6) Mehta, G.; Srikrishna, A.; Reddy, A. V.; Nair, M. S. *Tetrahedron* **1981**, *37*, 4543.

135.10 (s), 150.82 (s), 157.42 (d), 159.66 (s), 170.07 (s), 197.38 (s). Anal. Calcd for $C_{15}H_{13}ClO_4$: C, 61.55; H, 4.48. Found: C, 61.27; H, 4.33.

X-ray Structure of 6. All X-ray data were collected on a Nicolet R3m/μ update of a $P2_1$ diffractometer with use of Mo Kα monochromated radiation. Crystal data: a = 4.577 (1) Å, b = 12.298 (2) Å, c = 24.253 (4) Å, space group $P2_1cn$, Z = 4, D(calcd) = 1.647 g cm^{-3}, and μ = 30.04 cm^{-1}. Emprical absorption correction was applied. The structure of **6** was refined by the block-cascade least-squares technique with hydrogen atoms allowed to ride at fixed distances from attached atoms. Refinement: R = 0.0410 for 184 parameters and 831 reflections, S = 1.05, $(\Delta/\sigma)_{max}$ = 0.012 with the largest residual peaks from a final difference map of −0.43 and +0.33 e Å^{-3}.

Acknowledgment. Financial support of this study by the Air Force Office of Scientific Research (Grant AFOSR-88-0132, A.P.M.), the Robert A. Welch Foundation (Grant B-963, A.P.M.; Grant P-074, W.H.W.), and the University of North Texas Faculty Research Committee (A.P.M.) is gratefully acknowledged.

Registry No. **4**, 116970-42-4; **5**, 116970-43-5; **6**, 116970-44-6; **7**, 116970-45-7; EDA, 623-73-4.

Supplementary Material Available: A structure drawing of **6** with thermal ellipsoids drawn at the 35% probability level and a list of atomic coordinates and isotropic thermal parameters, bond lengths, bond angles, anisotropic thermal parameters, and H-atom coordinates and isotropic thermal parameters for **6** (7 pages); a list of structure factors for **6** (7 pages). Ordering information is given on any current masthead page.

Polyfunctional Diterpene Isonitriles from Marine Sponge *Acanthella carvenosa*

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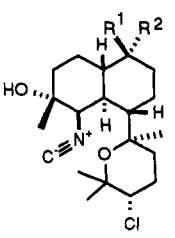
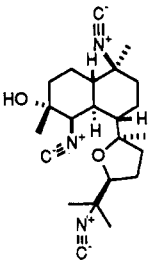
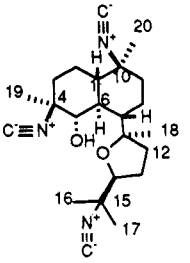
Received July 12, 1988

Orange sponges are conspicuous inhabitants of Fiji coral reefs. In 1984, our attention was drawn to an abundant, round orange Fijian sponge because its crude extracts were extremely active in an in vitro anthelmintic primary screen against parasitic stages of *Nippostrongylus brasiliensis*.[1] Bioassay guided isolation of the active constituents of this sponge, identified as *Acanthella carvenosa*,[2] commenced and involved both the original collection as well as large recollections made during two subsequent expeditions to Fiji in 1986 and 1987. While our work was in progress, Scheuer[3] reported structures of 11 richly functionalized diterpenoid antibiotics, the kalihinols, from Pacific collections of *Acanthella* sp. Structurally, the kalihinols fall into two main groups, the tetrahydropyran kalihinols, represented by kalihinol A (**1**),[3a] and the tetrahydrofuran kalihinols, represented by kalihinol F (**2**).[3b] Common to both groups is a *trans*-decalin skeleton bearing a hydroxyl function at carbon C-4; while multiple isocyano functions at C-5 and C-10 are found in seven cases. All five compounds of the first group have a chlorine atom at C-14 of the tetrahydropyranyl moiety, whereas in the second group the tetrahydrofuran moiety is functionalized at C-15 with NC, NCS, or Cl, or the *gem*-dimethyl is replaced by an isopropenyl. We now extend the structural breadth of this diterpenoid family by reporting the structure of a new tetrahydrofuran, isokalihinol F (**3**).







1 R_1=NC, R_2=Me
4 R_1=Me, R_2=NCS
5 R_1&R_2 = $=CH_2$
6 R_1=Me, R_2= NC

2 **3**

Results and Discussion

Aqueous methanol extracts of freshly collected sponge *A. carvenosa* yielded a dark viscous oil. The crude oil was then purified between aqueous methanol and the series: hexanes, CCl_4, and CH_2Cl_2. Purification proceeded on the dichloromethane partition fraction, which showed high in vitro anthelmintic activity. The workup of collection no. 86-8 illustrates our purification strategy. Its CH_2Cl_2 partition fraction was subjected to flash chromatography (silica gel) followed by repeated reversed-phase HPLC (10 μm ODS, 25 × 1.0 cm; 85% MeOH–15% H_2O), which afforded a major crystalline component, kalihinol A (**1**), whose spectral properties were identical with those reported by Scheuer.[3] Other minor components were obtained including known kalihinols F (**2**) and X (**4**) and an unknown compound, **3**. The latter crystallized as colorless long needles from diethyl ether (mp 180–182 °C; $[\alpha]^{20}_D$ +13.6°). Its molecular formula, $C_{23}H_{33}N_3O_2$ (calcd MW 383.257), was deduced from LRCIMS (isobutane) data, m/z 384 (M^+ + H) and an integrated ^{13}C NMR spectrum. The ^{13}C (C_6D_6) NMR spectrum of compound **3** showed a resemblance to that of kalihinol F (**2**). Most importantly, the resonances for **3** at 87.5 (s) (C-11) and 82.4 (d), (C-14) ppm were consistent with a tetrahydrofuran moiety, and broad triplets ($J \approx 5$ Hz) at 61.5, 59.8, and 59.6 ppm intimated that an isocyano group was attached to each of these carbons. A *trans*-decalin ring was assigned to **3** on biogenetic grounds and because of its similar ^{13}C NMR δ's with **2** at C-1, C-2, C-9, and C-20. However, in contrast to **2**, the three isocyano functions in **3** were assigned to carbons C-4, C-10, and C-15, while a secondary hydroxyl function, as a sharp ^{13}C NMR peak at 76.7 (d) ppm (whose methine ^1H was at δ 3.44), was assigned to carbon C-5. The specific evidence supporting the placement of the OH at C-5 and its assigned stereochemistry is as follows. The 2D ^1H–^1H homo and ^{13}C–^1H hetero COSY NMR spectra in C_6D_6 enabled all NMR resonances of **3** to be assigned. The ^1H–^1H COSY NMR spectrum showed strong correlations from ^1H NMR peak at 3.44 ppm (dd, J = 8.4, 3.3 Hz, H-5) to the peak at 0.95 ppm (m, H-6), and to the hydroxyl peak at 6.2 ppm (d, J = 3.3 Hz). A large coupling constant (J = 8.4 Hz) was observed between proton H-5 and axial H-6, which indicated that H-5 must also be axial. The remaining stereochemical features were next confirmed. The stereochemistry of the tetrahydrofuranyl ring substituents

(1) We thank Dr. Tom Matthews and his staff for this data according to the assay described by: Jenkins, D. C.; Armitage, R.; Carrington, T. S. *Z. Parasitenkd.* **1980**, *63*, 261.

(2) Our collections of *Acanthella carvenosa* (Fam. Axinellidae, Order Axinellida) were identified by C. Diaz (Harbor Branch Oceanographic Institution/SeaPharm Project, Fort Pierce, FL).

(3) (a) Chang, C. W. J.; Patra, A.; Roll, D. M.; Scheuer, P. J.; Matsumoto, G. M.; Clardy, J. *J. Am. Chem. Soc.* **1984**, *106*, 4644. (b) Patra, A.; Chang, C. W. J.; Scheuer, P. J.; van Duyne, G. D.; Matsumoto, G. M.; Clardy, J. *J. Am. Chem. Soc.* **1984**, *106*, 7981. (c) Chang, C. W. J.; Patra, A.; Baker, J. A.; Scheuer, P. J. *J. Am. Chem. Soc.* **1987**, *109*, 6119.

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