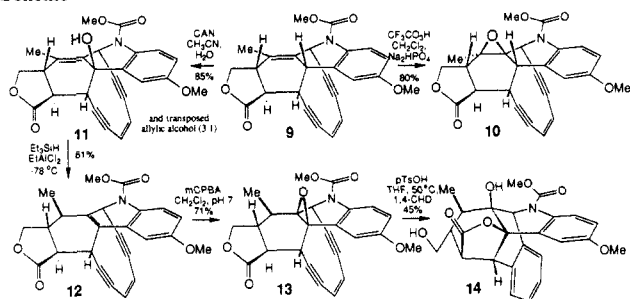**Scheme II**

THF) resulted in the trisubstituted dihydroquinoline derivative **6** in 60% overall yield. An X-ray crystallographic analysis of a related heterocycle **6a** (mp 151–152 °C), prepared by a similar reaction sequence, provided evidence for the 2,3,6-trisubstitution pattern and revealed the axial orientation of the acetylene moiety, as anticipated on consideration of allylic ($A^{(1,3)}$) strain[12] that would exist with the equatorially disposed conformer (Figure 1B).[13] Such an orientation was considered desirable for subsequent cyclization reactions. Next, **6** was converted to the cyclization substrates **7** and **8** by carbon–oxygen and carbon–carbon coupling processes, respectively.

Subjection of **7** to the Sonogashira[14] coupling conditions or **8** to the Yamaguchi macrolactonization protocol[15] was hoped to afford the corresponding macrolactone (Figure 1A). Instead, both reactions provided, at room temperature, the product of an apparent transannular Diels–Alder reaction (**9**).[16] Verification of structure followed X-ray crystallographic analysis (Figure 1C) and revealed the bending of the ring acetylenes that is characteristic of the enediyne antibiotics.[13] In contrast to the transannular Diels–Alder reaction, attempted intramolecular Diels–Alder reaction of the methyl ester, *tert*-butyldimethylsilyl ether of **8** failed entirely; slow decomposition occurred instead at temperatures above 180 °C.

Having secured a simple and efficient route to the target dynemicin A model system, we next investigated preliminary functionalization reactions of **9**. An epoxide trigger to the acetylene coupling (Bergman) reaction was installed by the reaction of **9** with anhydrous trifluoroperacetic acid in CH_2Cl_2, which afforded **10** in 80% yield. Translocation of the dynemicin-type epoxide to a calicheamicin-type epoxide (as found in **10**) results in a thermally activatible substrate for the Bergman reaction; the details of this process will be reported elsewhere. In order to examine the positional epoxide isomer found in dynemicin A, isomerization of the tetrasubstituted olefin was required. This was achieved by the oxidation–reduction sequence shown in Scheme II. Benzylic hydroxylation of **9** with ceric ammonium nitrate provided a mixture of **11** and an allylic alcohol isomer (3:1 ratio) in 85% yield. Reaction of either the individual isomers or the 3:1 mixture with Et_3SiH and $EtAlCl_2$ provided a 61% yield of **12** and **9** in an 8:1 ratio. Epoxidation of **12** with mCPBA in a buffered medium resulted in the formation of the stable dynemicin-like epoxide **13**, whose structure was confirmed by X-ray

diffractometry (Figure 1D), in 71% yield. Treatment of **13** with pTsOH and 1,4-cyclohexadiene in THF (50 °C, 10 h) resulted in the predominant formation of **14** (45%), which has undergone epoxide ring opening, Bergman aromatization, and translactonization.

The transannular Diels–Alder reaction appears well suited to access structures related to the enediyne family of natural products. Efforts to extend this research are now underway.

Synthesis and Characterization of Hexamethyltellurium(VI)

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Peralkylated derivatives of hexavalent transition metals, compounds such as $W(CH_3)_6$ and $Re(CH_3)_6$,[1] have been known for many years; however, the analogous main-group compounds, species like $Te(CH_3)_6$ or $Se(CH_3)_6$, have not been previously reported. Within the main-group elements, $Sb(CH_3)_5$ and $As(CH_3)_5$ have been well characterized[2,3] and a very few perfluoroalkyl and aryl Te(VI) polyfluorides have been prepared,[4] but until the very recent synthesis of $Te(CH_3)_4$,[5] even peralkylated derivatives of Te(IV) were unknown. We report the synthesis, isolation, and characterization of $Te(CH_3)_6$, the first peralkylated hexavalent derivative of one of the representative elements.

Synthesis of $TeF_2(CH_3)_4$.[6] Under an inert atmosphere, XeF_2,[7] 0.359 25 g (2.1220 mmol), was placed into a 10-mL flask that was equipped with a Teflon valve. The flask was degassed, and then $Te(CH_3)_4$, 0.319 65 g (1.7026 mmol), and dry CH_3CN, 5 mL, were added. The solution was stirred at −30 °C for 2 h and then at ambient temperature for 1 h. All of the materials volatile at 0 °C were removed, which left a white solid, $TeF_2(CH_3)_4$, 0.333 05 g (1.4754 mmol), 87%.

The mass spectral and NMR data for this new compound are contained in Tables I and II. Exact mass for the m/e 213 ion ($^{130}TeF_2(CH_3)_3^+$): calcd 212.9739, measd 212.9741; $\Delta_m/_m = 0.9$

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(11) Prepared by the following reaction sequence: (a) *cis*-1,2-dichloroethylene, $Pd(PPh_3)_4$ (5%), (thexyldimethylsilyl)acetylene, $nPrNH_2$, CuI (15%), benzene, 75%; (b) (trimethylsilyl)acetylene, $Pd(PPh_3)_4$ (5%), $nPrNH_2$, CuI (15%), benzene, 93%; (c) $AgNO_3$, EtOH, H_2O; KCN (80%); (d) BuLi (−78 °C); $MgBr_2$–Et_2O (0 °C).

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(5) Gedridge, R. W.; Harris, D. C.; Higa, K. T.; Nissan, R. A. *Organometallics* **1989**, *8*, 2817.

(6) All manipulations of compounds were carried out either in a glove bag or on a vacuum line. Chemical shifts were measured vs external TMS (^{1}H and ^{13}C), TFA (^{19}F), or $Te(CH_3)_2$ (^{125}Te).

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Table I. Mass Spectral Data for Te(CH₃)₆, TeF₂(CH₃)₄, and Te(CH₃)₄

TeMe₆[a]			TeF₂Me₄[a]			Te(Me)₄[a,b]		
mass	ion	% abundance	mass	ion	% abundance	mass	ion	% abundance
206	TeMe₅H⁺	2.0				175	TeMe₃⁺	15.6
205	TeMe₅⁺	55.9	213	F₂TeMe₃⁺	63.0	160	TeMe₂⁺	100
176	TeMe₃H⁺	1.8	209	FTeMe₄⁺	47.8	146	TeMeH⁺	5.4
175	TeMe₃⁺	100	183	F₂TeMe⁺	20.8	145	TeMe⁺	81.3
161	TeMe₂H⁺	2.1				131	TeH⁺	15.6
160	TeMe₂⁺	61.0	179	FTeMe₂⁺	100	130	Te⁺	18.8
146	TeMeH⁺	2.5	164	FTeMe⁺	9.5			
145	TeMe⁺	29.7	160	TeMe₂⁺	48.0			
131	TeH⁺	6.8	145	TeMe⁺	37.4			
130	Te⁺	5.1	131	TeH⁺	6.5			
			130	Te⁺	6.8			

[a] Spectra were obtained from an AEI MS-30 instrument at 70 eV. The EI source was operated at ambient temperature. Reported intensities are based upon the ¹³⁰Te isotope (34.48%). Aside from those reported here, no other ions were detected. [b] Previously unreported.

Table II. Nuclear Magnetic Resonance Data for Alkylated Tellurium Compounds[a]

compd	δ ¹²⁵Te	δ ¹³C	δ ¹H	δ ¹⁹F	²J_{Te-H}	¹J_{Te-C}	¹J_{C-H}	¹J_{Te-F}
Te(CH₃)₂[b]	0.0	−21.5	1.83		20.8	158.5	140.7	
Te(CH₃)₄[b]	−67	20.6	0.99		34.0	127.8	133.4	
Te(CH₃)₆[c]	21.7 (m)	37.1 (q)	1.26 (s)		3.0	38.2	131.7	
TeF₂(CH₃)₄[c]	592 (t)	36.4 (m)	1.24 (s)	84.0 (s)	43.7	−	−	1830
		25.6 (br)	2.07 (s)		44.3	−		

[a] Chemical shifts in parts per million; coupling constants in hertz; s = singlet, t = triplet, q = quartet, br = broad, m = multiplet. [b] From refs 5 and 10. [c] In C₆D₆.

ppm. Mp (sealed tube): 73 °C.

Synthesis of Te(CH₃)₆. Under N₂, cis-TeF₂(CH₃)₄, 0.233 05 g (1.0324 mmol), was added to a 10-mL flask and degassed, and then Zn(CH₃)₂, 0.151 60 g (1.5884 mmol), and diethyl ether, 5 mL, were added. The solution was stirred magnetically for 2 h at 0 °C and then separated. Hexamethyltellurium, 0.153 87 g (0.7064 mmol), 68%, a volatile white solid that is retained at −23 °C, was separated by fractionation. The low-resolution mass spectral and NMR data (Figure 1) are summarized in Tables I and II.

Ir (in CCl₄): 2994 (s), 2909 (s), 2786 (w), 2391 (w), 2337 (m), 1630 (w), 1472 (w), 1406 (m), 1185 (s), 807 (s), and 469 (s) cm⁻¹. Exact mass for the m/e 205 ion (¹³⁰Te(CH₃)₅⁺): calcd 205.0241, measd 205.0238; Δm/m = 1.5 ppm. Exact mass for the m/e 203 ion (¹²⁸Te(CH₃)₅⁺): calcd 203.0221, measd 203.0220; Δm/m = 0.5 ppm.

Reaction of Te(CH₃)₆ with Br₂. Under N₂, Te(CH₃)₆, 0.024 95 g (0.1146 mmol), was placed in a reactor and degassed, and then bromine, 1.406 60 g (8.8018 mmol), was added. The vessel was held at −78 °C for 0.5 h and warmed to ambient temperature for 0.5 h, and then the contents were separated by fractionation. Methyl bromide, 0.065 20 g (0.6868 mmol), was identified by ¹H NMR data and by mass spectrometry. The TeBr₄ that was generated was reacted with excess HNO₃ at 140 °C, and then the TeO₂ formed, 0.018 25 g (0.1144 mmol), was dried and weighed. The experimental Te/CH₃ ratio in Te(CH₃)₆ is 1.00/6.00. Analysis for Te in Te(CH₃)₆: calc 58.6%, found 58.5%.

Thermal Stability of Te(CH₃)₆. A sample consisting of Te(CH₃)₆, 10% in C₆D₆, was heated in a sealed Pyrex vessel to 140 °C for 4.5 h. Proton NMR spectra indicated that the Te(CH₃)₆ was unchanged.

The first reaction described above demonstrates that XeF₂ cleanly oxidizes Te(CH₃)₄ to TeF₂(CH₃)₄ in high yields. Gaseous Xe is the only other product observed. The NMR data unequivocally indicate that the fluorine ligands are cis in the difluoride. Tetramethyltellurium(VI) difluoride is a sublimable white solid that is stable for several days in the absence of air. The 70-eV mass spectra (Table I) do not contain molecular ions, but both the TeF₂(CH₃)₃⁺ and the TeF(CH₃)₄⁺ ions are reasonably prominent in the spectrum. The relative intensities of hydride-containing ions, e.g., TeH⁺, present in the 70-eV spectrum can be easily decreased by a reduction of the electron voltage.

If TeF₂(CH₃)₄ is not separated from the reaction mixture for several hours, a second Te-containing species, TeF₃(CH₃)₃, is generated by the reaction of TeF₂(CH₃)₄ with the HF formed from
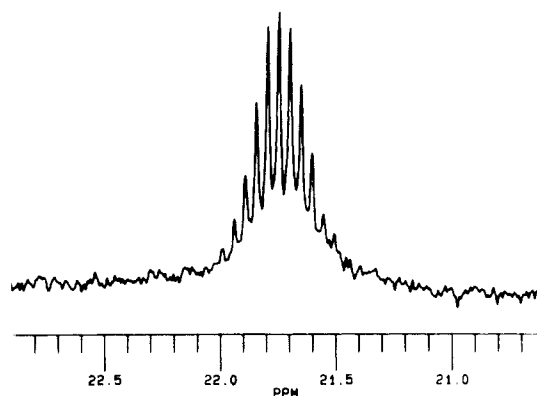
Figure 1. The ¹²⁵Te NMR spectrum of Te(CH₃)₆. The ²J_{Te-H} coupling constant is 3.0 Hz. Only 11 of the anticipated 19 lines are evident in the ¹²⁵Te spectrum, but these 11 lines contain 99.247% of the total intensity of the Te resonance.

XeF₂ and the solvent, CH₃CN. The ¹⁹F NMR data for the trifluoride (100.3 (t) ppm, 1 F, J_{Te-F} = 2677 Hz; 10.0 (d) ppm, 2 F, J_{Te-F} = 1752 Hz, J_{F-F} = 40 Hz) clearly indicate the meridional stereochemistry.

The reaction of TeF₂(CH₃)₄ with Zn(CH₃)₂ in diethyl ether results in Te(CH₃)₆, a colorless volatile solid. As was found for Te(CH₃)₄ and TeF₂(CH₃)₄, Table I, the molecular ions for Te(CH₃)₆ are not observed in the low-resolution mass spectrum,[8] but the exact mass data prove the attachment of five CH₃ groups to the Te atom, and the bromination reaction shows that the sixth ligand is also a methyl group. All of the currently available evidence is consistent with octahedral coordination of the ligands about the Te(VI) centers in each of the new compounds discussed here.

The reactivity of hexavalent tellurium compounds is currently under intensive investigation, but one of the more interesting aspects, the stability of the Te(VI) alkyl derivatives, is already evident. Methyl for F ligand exchanges and their reverse occur easily without concurrent reduction. In addition, Gedridge[5] has

(8) Molecular ions are also unobserved in the 70-eV mass spectra of TeF₆, TeBrF₅,[9] and W(CH₃)₆.[1]

(9) Fraser, G. W.; Peacock, R. D.; Watkins, P. M. *J. Chem. Soc., Chem. Commun.* **1968**, 1257.

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shown that Te(CH$_3$)$_4$ completely decomposed after 4 h at 120 °C. Since, as shown above, the Te(CH$_3$)$_6$ sample in C$_6$D$_6$ survived for 4.5 h at 140 °C unchanged, Te(CH$_3$)$_6$ is clearly much more thermally stable than Te(CH$_3$)$_4$.
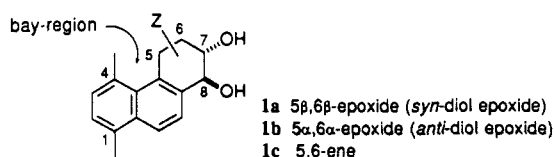
A Novel Regio- and Stereocontrolled Synthesis of Diol Epoxide and *trans*-Dihydrodiol Metabolites of Polycyclic Aromatic Hydrocarbons. An Application to the Synthesis of the Bay-Region *syn*- and *anti*-Diol Epoxides of the Carcinogen 1,4-Dimethylphenanthrene[†]

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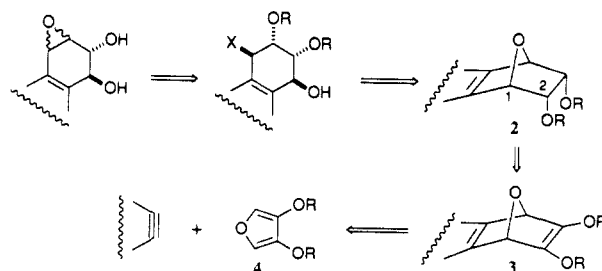Ann Arbor, Michigan 48109*

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Carcinogenic polycyclic aromatic hydrocarbons (PAHs) require metabolic activation in order to exert their tumorigenic activity, typically to the diol epoxides[1] as predicted by the bay-region concept.[2] While a number of synthetic methods toward these

1a 5β,6β-epoxide (*syn*-diol epoxide)
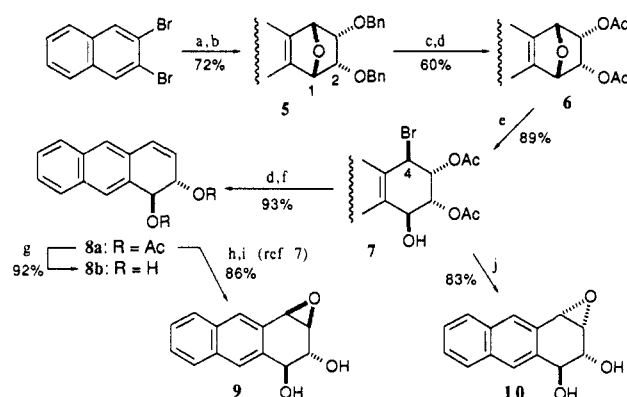**1b** 5α,6α-epoxide (*anti*-diol epoxide)
1c 5,6-ene

diol epoxides are described in the literature,[3] it was felt that a new, entirely different approach may be needed that achieves regio- and stereochemically controlled synthesis of these metabolites, particularly the bay-region analogues. In the following we delineate a generally applicable, efficient synthesis of PAH diol epoxides and *trans*-dihydrodiols and its application to the first synthesis of the putative active metabolites, the bay-region diol epoxides of the carcinogen 1,4-dimethylphenanthrene (1,4-DMPh).[4]

Our strategy is illustrated in Scheme I in the form of retrosynthetic analysis. This approach entails (1) the initial cycloaddition between an aryne and a 3,4-dialkoxyfuran, (2) the stereoselective hydrogenation of the cycloadduct **3** from the exo side, and (3) the regioselective ether-bridge opening of **2** with a ster-

[†] Dedicated to Professor Koji Nakanishi on the occasion of his receipt of the 1990 Cope Award from the American Chemical Society and the 1990 Imperial Prize of Japan Academy.

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(2) Lehr, R. E.; Kumar, S.; Levin, W.; Wood, A. W.; Chang, R. L.; Conney, A. H.; Yagi, H.; Sayer, J. M.; Jerina, D. M. In: Reference 1, pp 63–84.

(3) (a) Harvey, R. G. In: Reference 1, pp 35–62. (b) Harvey, R. G. *Synthesis* **1986**, 605.

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(7) (a) Yagi, H.; Hernandez, O.; Jerina, D. M. *J. Am. Chem. Soc.* **1975**, *97*, 6881. (b) Yagi, H.; Thakker, D. R.; Hernandez, O.; Koreeda, M.; Jerina, D. M. *Ibid.* **1977**, *99*, 1604.

Scheme I

Scheme II[a]

[a]Conditions: (a) **4** [R = Bn (ref 5); 2.5 equiv], *n*-BuLi (1.1 equiv)/THF, –78 °C → room temperature, 12 h; (b) H$_2$/PtO$_2$, benzene/EtOH, room temperature, 4 h; (c) BF$_3$·Et$_2$O (4.2 equiv), EtSH (70 equiv)/CH$_2$Cl$_2$, 0 °C, 6 h; (d) Ac$_2$O/pyridine, room temperature, overnight; (e) BBr$_3$ (1.5 equiv)/CH$_2$Cl$_2$, 0 °C, 30 min; (f) Cr(ClO$_4$)$_2$, ethylenediamine/DMF, 0 °C, 20 min (ref 6); (g) NH$_3$/MeOH, 0 °C → 10 °C, 3 h; (h) *N*-bromoacetamide (NBA)/20% aqueous THF, 0 °C, 4 h; (i) NaOMe (1.2 equiv)/THF, MeOH, room temperature, 2 h; (j) same as (i), 1 h.

Scheme III[a]

12a/b   **13a/b**   **14a/b**
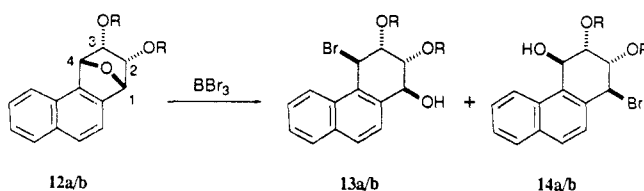
[a]a series, R = Ac; b series, R = O(C=O)O.

eocontrolled incorporation of an appropriate nucleophile. It should be noted that the trans relationship between the two oxygen groups at C-1 and -2 in **2** forms the basis of our synthetic strategy toward these PAH metabolites.

In an effort to assess the feasibility of this approach, the synthesis of the diol epoxides and *trans*-dihydrodiols of the linear PAHs naphthalene and anthracene was probed. Interestingly, the synthesis of the diol epoxides of anthracene has not been reported in the literature, presumably due to the lack of tumorigenic activity of anthracene. These derivatives of both naphthalene and anthracene can be efficiently synthesized, as summarized in Scheme II for the anthracene series, under complete stereochemical control based on the aryne 3,4-bis(benzyloxy)furan cycloaddition approach. Thus, the synthesis of *syn*-**9** and *anti*-diol epoxides **10** and 1,2-*trans*-dihydrodiol **8b** of anthracene has been efficiently achieved from 2,3-dibromonaphthalene in 31, 32, and 33% overall yields, respectively.[8]

Unlike the examples described above, the physiologically more potent PAH diol epoxides have the epoxide group in the bay region. Therefore, the application of the present methodology in the

(8) Both naphthalene *syn*- and *anti*-diol epoxide derivatives have also been synthesized in a similar manner from 1-(tosyloxy)-2-bromobenzene in comparable yields.