porphine (TpFPP), tetra(*p*-chlorophenyl)porphine (TpClPP), tetra(*p*-bromophenyl)porphine (TpBrPP), and tetra(*p*-iodophenyl)porphine (TpIPP) indicated medium-strength halogen-sensitive bands in the 1050–1100-cm^{-1} region for TpClPP, TpBrPP, and TpIPP. These bands corresponded to relatively strong infrared bands and relatively weak resonance Raman bands or shoulders in spectra of solid porphyrin dications, solid neutral porphyrins, and solid copper(II) porphyrins (Table I). The same bands have been reported previously as halogen-sensitive infrared bands of TpClPP and TpBrPP[18] and are found in the infrared and Raman spectra of all chlorine-, bromine-, and iodine-containing benzenes and asymmetrically para-disubstituted benzenes[19] (see Table I for examples). Most investigators[19a,c-e] assigned these bands to phenyl ring vibration modes which involve significant extents of C–X stretching motion. Reported[18] fluorine-sensitive bands could not be tested for in resonance Raman spectra because of interfering bands common to all of the tetraarylporphines examined, but TpFPP as well as TPP served as control compounds for comparisons with TpClPP, TpBrPP, and TpIPP. (To further test the correlations, we examined the infrared spectrum of solid tetra(*o*-chlorophenyl)porphine (ToClPP) for a halogen-sensitive band predicted from the infrared and Raman spectra[19c,d] of ortho-disubstituted, chlorine-containing benzene derivatives; the predicted band was observed in the infrared spectrum of the neutral porphyrin but not in the resonance Raman spectrum of the dication in solution. Perhaps *o*-chloro steric effects in ToClPP force the porphyrin–phenyl dihedral angles to close to 90°, thus minimizing π delocalization.) The assignment of 1050–1100-cm^{-1} region halogen-sensitive bands to phenyl ring vibrations which have appreciable C–X stretching character has been confirmed for *p*-chlorofluoro-, *p*-bromofluoro-, and *o*-chlorofluorobenzene by normal coordinate analysis; the normal coordinate analysis did not include iodine-containing compounds.[20] Earlier workers[21] had assigned infrared bands in the 490–510-cm^{-1} region to C–Cl stretching vibrations in TpClPP and metallo TpClPP derivatives by analogy to the infrared spectra of aliphatic compounds; bands in this region instead may be associated with vibrations involving significant C–Cl bending character.[20] Lack of consistency in literature assignments[19,20] of vibrational frequencies associated with halogen motion in meta-disubstituted halogen-containing benzenes precluded our use of tetra(*m*-halophenyl)porphines.

The resonance Raman results provide direct evidence for π delocalization linking *meso*-aryl groups to the porphyrin ring system in porphyrin dications, neutral porphyrins, and copper(II) porphyrins. These results are consistent with previous experimental[7,9a] and calculational[22] evidence. Apparently even dihedral angles over 80° do not preclude π delocalization. Magnetic resonance studies on iron(III) porphyrins[9b] and linear free-energy correlations for nickel(II), vanadyl(IV), and cobalt(II) porphyrins[23] suggest that other metalloporphyrins will exhibit resonance Raman bands associated with *meso*-phenyl substituents. Our results indicate that neither bonding nor resonance energy calculations should ignore π delocalization involving phenyl substituents in tetraarylporphines.

Acknowledgments. Acknowledgment is made to the donors of the Petroleum Research Fund, administered by the American Chemical Society, for support of this research. We thank Professor N. C. Craig for aid and advice and Professor T. G. Spiro for permission to carry out some preliminary porphyrin dication experiments in his laboratory.

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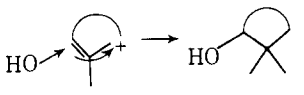
Seven-Membered Rings via Silyl Enol Ether Participation in the Olefin Cyclization. Anti-Markownikoff Cyclization in Biomimetic Terpene Synthesis

Sir:

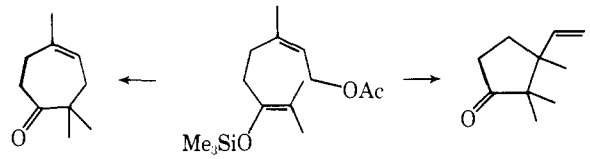
In light of the crucial role of anti-Markownikoff cyclization in terpene biosynthesis (eq 1), of which enzymic formations



(1)

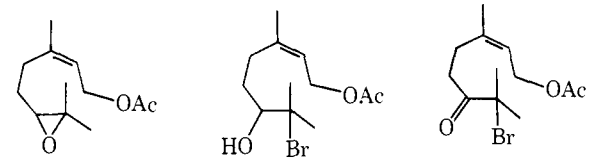
of karahanaenone,[1] humulene,[2] and lanosterol (C ring)[3] are the most notable examples, it is surprising that there seems to be no appropriate chemical precedent for such processes. We have been intrigued for some time in the possibility of terminating cationic cyclization via nucleophilic participation of silyl enol ether which, if successful, would result in the formation of several cyclic terpenes otherwise directly unattainable.[4] The present communication describes the initial results which show the feasibility and some limitations of this methodology.

Since neryl acetate has been shown to undergo facile organoaluminum-promoted cyclization to give a good yield of limonene,[5] we selected to examine the cyclization of the acetate **1** using several different organoaluminum reagents. In that event, it was not clear a priori, whether there would be a preference for formation of a seven- or five-membered ring via the primary or tertiary cation, respectively.



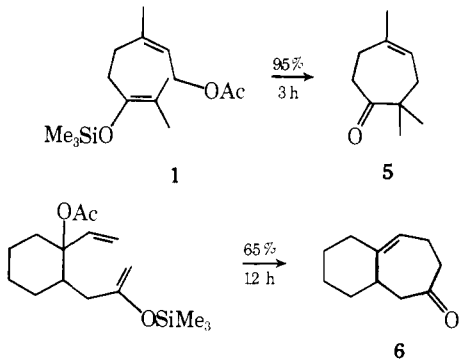
1

For the synthesis of **1,** the bromohydrin **3** was required as the precursor of the bromo ketone which was to serve for the generation of the necessary enolate.[6] The epoxy acetate **2,** readily available by control oxidation of neryl acetate,[7] was converted to the desired bromohydrin **3** by exposure to 47% hydrobromic acid in benzene at 25 °C for 15 min (75% yield).[8,9] The structure of **3,** the product of ring opening without cyclization, followed from its spectral properties (IR (liquid film) 3500 cm^{-1}; NMR (CCl_4) δ 1.73 (br s, 9 H)). Oxidation of the alcohol **3** by the method of Corey and Kim[10] gave, in 94% yield,[8] the bromo ketone **4:** IR (liquid film) 1740, 1710 cm^{-1}; NMR (CCl_4) δ 1.75 (s, 3 H), 1.84 (s, 6 H), 1.96 (s, 3 H). Regiospecific formation of the silyl enol ether was effected by reduction of the bromo ketone **4** with zinc dust in the presence of trimethylsilyl chloride in dry tetrahydrofuran (25 °C for 1 h)[11] followed by addition of excess pyridine prior to workup,[12] which gave, in 80% yield,[8] the silyl enol ether **1** as a colorless liquid: IR (liquid film) 1740, 1682 cm^{-1}; NMR (CCl_4) δ 0.17 (s, 9 H), 1.53 (s, 3 H), 1.58 (s, 3 H), 1.74 (s, 3 H), 1.95 (s, 3 H), 2.17 (br s, 4 H), 4.30 (d, 2 H, J = 7 Hz), 5.26 (t, 1 H, J = 7 Hz).



2 3 4

Trimethylaluminum (as a ~1 M solution in hexane) was pretreated with trifluoroacetic acid (molar ratio 1:2) in hexane at 0 °C initial temperature with gradual warming to 25 °C,[13] and to the resultant methylaluminum bis(trifluoroacetate) was added the allylic acetate **1** (0.25 equiv) in dry methylene chloride at 0 °C. After 10 min at 0 °C and 3 h at 25 °C, no starting material was left and the product from **1** turned out to be an essentially pure karahanaenone (**5**) (95% yield by GLC analysis).[14,15] On treatment at 25 °C for 3–10 min with $AlCl_3$, Et_2AlCl, $TiCl_4$, or $SnCl_4$ in hexane, the same ketone **5** was also generated in up to 85% yield (GLC analysis).[16] An overall process may be closely related to that by which the same category of cycloheptenone is believed to be formed enzymically from neryl pyrophosphate or its functional equivalent. Under the similar conditions, the bicyclic ketone **6** was produced in 65% isolated yield:[8] IR (liquid film) 1705 cm^{-1}.

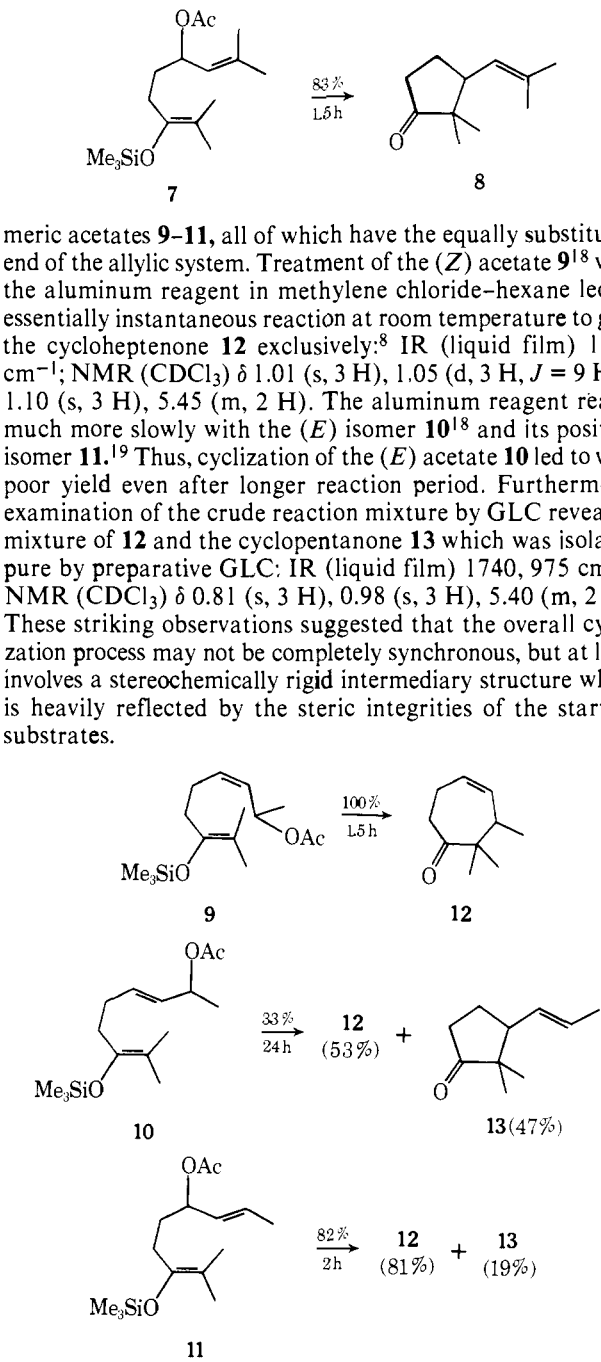


1 5

6

A dramatic alteration in the mode of cyclization was observed when the reaction of methylaluminum bis(trifluoroacetate) was conducted with the allylic acetate **7.**[17] The product, isolated in 83% yield, appeared by GLC to be >99% pure cyclopentanone **8:**[8] IR (liquid film) 1745 cm^{-1}; NMR ($CDCl_3$) δ 4.87 (br d, 1 H, J = 9 Hz). Thus, the alkylation introduces the new C–C bond with a preference for the less substituted end of the allylic system.

More detailed investigation was carried out with the isomeric acetates **9–11,** all of which have the equally substituted end of the allylic system. Treatment of the (*Z*) acetate **9**[18] with the aluminum reagent in methylene chloride–hexane led to essentially instantaneous reaction at room temperature to give the cycloheptenone **12** exclusively:[8] IR (liquid film) 1704 cm^{-1}; NMR ($CDCl_3$) δ 1.01 (s, 3 H), 1.05 (d, 3 H, J = 9 Hz), 1.10 (s, 3 H), 5.45 (m, 2 H). The aluminum reagent reacts much more slowly with the (*E*) isomer **10**[18] and its position isomer **11.**[19] Thus, cyclization of the (*E*) acetate **10** led to very poor yield even after longer reaction period. Furthermore, examination of the crude reaction mixture by GLC reveals a mixture of **12** and the cyclopentanone **13** which was isolated pure by preparative GLC: IR (liquid film) 1740, 975 cm^{-1}; NMR ($CDCl_3$) δ 0.81 (s, 3 H), 0.98 (s, 3 H), 5.40 (m, 2 H). These striking observations suggested that the overall cyclization process may not be completely synchronous, but at least involves a stereochemically rigid intermediary structure which is heavily reflected by the steric integrities of the starting substrates.



7 8

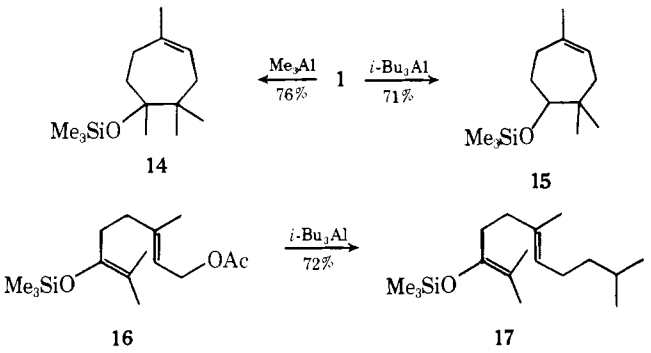
9 12

10 13 (47%)

11

Subjection of the acetate **1** to the action of trimethylaluminum (4 equiv) in hexane at 0 °C for 30 min resulted in formation of the C-methylated silyl ether **14** (76% yield):[5,8] NMR ($CDCl_3$) δ 0.10 (s, 9 H), 0.82 (s, 3 H), 0.87 (s, 3 H), 1.18 (s, 3 H), 1.70 (br s, 3 H), 5.34 (t, 1 H, J = 7 Hz); mass m/e 240 (M^+). When the substrate **1** was exposed to triisobutylaluminum (4 equiv) in hexane at 0 °C for 15 min, the predominant product (71% yield)[8] was the silyl ether **15,** resulting from the unprecedented reductive cyclization:[20] NMR ($CDCl_3$) δ 0.10 (s, 9 H), 0.79 (s, 3 H), 0.88 (s, 3 H), 1.72 (s, 3 H), 3.35 (dd, 1 H, J = 4 and 7 Hz), 5.33 (t, 1 H, J = 7 Hz); mass m/e 226 (M^+). In contrast, treatment of the (*E*) isomer **16**[21] in hexane with excess triisobutylaluminum at 0 °C for 15 min furnished

the acyclic silyl ether **17** in 72% yield:[8] NMR ($CDCl_3$) δ 0.16 (s, 9 H), 0.87 (d, 6 H, J = 6 Hz), 1.60 (br s, 9 H), 5.10 (t, 1 H, J = 7 Hz); mass m/e 282 (M^+). Thus, again, the fate of cyclization is markedly affected by steric integrities of the allylic acetates.



The success of the approach illustrated in this communication has made it possible to consider several new biomimetic routes to terpenes as well as a fairly general route to various cycloheptenone derivatives.

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(6) Regiospecific formation of an enolate ion from the bromo ketone; see for other method G. Stork and M. Isobe, *J. Am. Chem. Soc.*, **97**, 4745 (1975).
(7) *m*-Chloroperbenzoic acid was added portionwise to a solution of neryl acetate (molar ratio, 1.05:1) in methylene chloride at 0 °C (80% yield); for a similar oxidation, see E. E. van Tamelene and J. P. McCormick, *J. Am. Chem. Soc.*, **92**, 737 (1970).
(8) Purification by chromatography on silica gel with ether–hexane.
(9) In polar ether solvents, the regioisomeric *tert*-alcohol was obtained as the major product.
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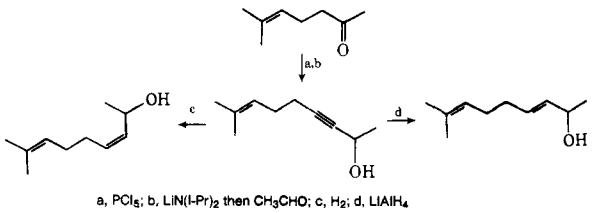
(11) G. C. Joshi and L. M. Pande, *Synthesis*, 450 (1975).
(12) Because of the acid sensitivity of the product, pyridine should be added to quench the reaction; for the similar example, see J. M. Denis, C. Girard, and J. M. Conia, *Synthesis*, 549 (1972).
(13) All operations involving organoaluminum reagents were conducted in an atmosphere of dry argon or nitrogen. In a typical preparation of this reagent, 4 mL of cooled solution of trimethylaluminum (1 M in hexane) was treated with trifluoroacetic acid (8 mmol) dropwise at 0 °C (exothermic reaction) (8 mmol of methane was evolved during this operation). After warming to 25 °C over ~10 min, the partially soluble reagent is ready for use in situ.
(14) The IR, NMR, and mass spectra of synthetic karahanaenone are identical with those of the natural ketone; see ref 1 and 4.
(15) None of the cyclopentanone derivative was detected by GLC and NMR analysis.
(16) The reaction should be quenched immediately after the disappearance of the starting acetate, since the product **5** was not sufficiently stable to survive in the presence of these Lewis acids.
(17) Using the same sequence of reactions for the preparation of **1**, the oily acetate **7** was obtained from 8,2-dimethyl-2,7-nonadien-4-ol which in turn was prepared from 6-methyl-5-hepten-2-one by the aldol condensation with acetone followed by $NaBH_4$ reduction.
(18) The acetate **9** and **10** were prepared according to the general route as nerol → **1**. The starting alcohols were synthesized as follows:



a, PCl_5; b, $LiN(i\text{-}Pr)_2$ then CH_3CHO; c, H_2; d, $LiAlH_4$

(19) The starting alcohol was prepared by the aldol condensation of 6-methyl-5-hepten-2-one with acetaldehyde followed by $NaBH_4$ reduction.
(20) Reductive termination of cationic cyclization appears to be unique in squalene biosynthesis; see L. J. Mulheirn and P. J. Ramm, *Chem. Soc. Rev.*, 1, 259 (1972).
(21) Prepared from geraniol.

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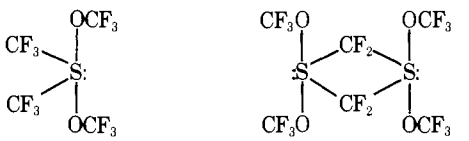
Two Stable Sulfuranes, $(CF_3)_2S(OCF_3)_2$ and $(CF_3O)_2SCF_2S(OCF_3)_2CF_2$

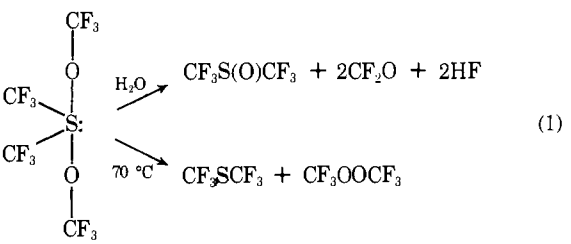
Sir:

Recently we have reported the synthesis of thermally stable chlorobis(dialkylamino)trifluoromethylsulfuranes[1] which are hydrolyzed slowly by water to form the trifluoromethyl(dialkylamino) sulfoxides. In our continuing studies of tri- and tetracoordinated sulfur(IV) compounds, it now has been possible to prepare bis(trifluoromethyl)bis(trifluoromethoxy)sulfurane (A), the first stable member of a new family of tetracoordinated sulfur(IV) compounds, by photolysis of a mixture of bis(trifluoromethyl) sulfide and trifluoromethyl hypochlorite. There is considerable interest in aryl sulfuranes based on reports concerned with the preparation,[2-6] the geometry at sulfur,[7] and the synthetic utility[8-11] of these compounds. Dialkyldialkoxysulfuranes have been suggested as intermediates in the chemistry of sulfonium salts.[12] Compounds which are formal derivatives of sulfur tetrafluoride and sulfur hexafluoride are stable and their geometries and reactivities have been well studied.[13,14]



A B

Bis(trifluoromethyl) sulfide[15] and trifluoromethyl hypochlorite[16] are condensed into a 100-mL quartz vessel and photolyzed for 20 h with a Hanovia utility ultraviolet quartz lamp. Bis(trifluoromethyl)bis(trifluoromethoxy)sulfurane (A) is retained in a trap at −78 °C by using trap-to-trap separation techniques. This sulfurane is a pale yellow liquid with an extrapolated boiling point of 72 °C from the equation $\log P_{Torr} = 7.32 + 1532/T$ (valid between 0 and 52 °C). The molar heat of vaporization is 7.0 kcal and the Trouton constant is 20.3 eu. It is stable in Pyrex glass at 25 °C for periods of a few days. However, in the presence of water, hydrolysis occurs to form bis(trifluoromethyl) sulfoxide[15] (86%) and carbonyl fluoride (83%). When heated at 70 °C for 1 h in a stainless steel Hoke vessel, bis(trifluoromethyl) sulfide and bis(trifluoromethyl) peroxide[17] are generated quantitatively (eq 1).



(1)

Spectroscopic data further support the existence of this new sulfurane (A). The ^{19}F NMR spectrum shows resonances at