°C (from petroleum ether). **5i**: 75%; mp 69–71 °C (from petroleum ether). Compound **5j** was obtained in low yield as oily product. The NMR and TLC showed the presence of small quantities of 2-*tert*-butylaniline. This contamination did not, however, interfere with kinetic measurements. **5k**: 56%; bp 96 °C (0.01 mm) [lit.[27] bp 92 °C (0.25 mm)]. Distillation of this product did not allow the removal of small quantities of unreacted *N*-methylaniline. After distillation the product was additionally purified by column chromatography (silica gel, chloroform–acetone, 9:1).

Kinetics. All kinetic measurements were done spectrophotometrically by recording the decrease in absorbance at 270–280 nm due to the disappearance of the starting material by using a Beckman UV 5260 spectrophotometer. Pseudo-first-order rate constants were obtained from the plots of ln $(A_t - A_\infty)$ vs. time in the usual manner. Excellent linearity ($r > 0.999$) was obtained in all cases. The identity of the reaction taking place and the identities of the products were determined by recording the UV spectra of the corresponding anilines in the reaction medium.

(27) V. A. Gilyarov, R. V. Kudryavtsev, and M. I. Kabachnik, *Zh. Obshch. Chim.*, **36**, 708 (1966).

Acknowledgment. Financial assistance of the University of Cape Town and the Council for Scientific and Industrial Research is gratefully acknowledged.

Registry No. 5a, 58046-12-1; **5b**, 25626-98-6; **5c**, 25626-99-7; **5d**, 25627-01-4; **5e**, 79639-85-3; **5f**, 75894-86-9; **5g**, 79639-86-4; **5h**, 79639-87-5; **5i**, 79639-88-6; **5j**, 79639-90-0; **5k**, 7006-95-3; dimethyl phosphorochloridate, 813-77-4; benzenamine, 62-53-3; 2-methylbenzenamine, 95-53-4; 3-methylbenzenamine, 108-44-1; 4-methylbenzenamine, 106-49-0; 3,4-dimethylbenzamine, 95-64-7; 2,6-dimethylbenzenamine, 87-62-7; 2-ethylbenzenamine, 578-54-1; 4-ethylbenzenamine, 589-16-2; 4-butylbenzenamine, 104-13-2; 2-(1,1-dimethylethyl)benzenamine, 6310-21-0; *N*-methylbenzenamine, 100-61-8.

Synthesis of Polycyclic Homocyclopropylcarbinols by Reductive Cyclization of Bromocyclopropyl Epoxides

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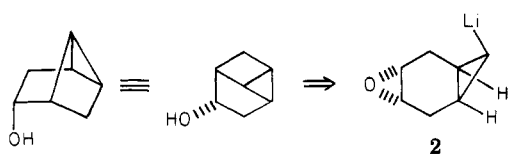
A new synthetic route to polycyclic homocyclopropylcarbinols has been realized by lithiation of bromocyclopropyl epoxides with *n*-butyllithium and subsequent intramolecular attack of the metalated cyclopropane ring onto the epoxide. A series of seven bromocyclopropyl epoxides was prepared from diene precursors in three or four steps by dibromocyclopropanation, epoxidation, and stereoselective reduction of one bromine atom. Thus, *endo*-7-bromobicyclo[4.1.0]hept-3-ene *anti*-oxide (**27**) prepared from 1,4-cyclohexadiene (**3**) underwent cyclization to *endo*-tricyclo[3.2.0.0^{2,7}]heptan-4-ol (**1**) in 69% yield. Three dimethyl derivatives of **1** (**34–36**) were synthesized in this manner from 1,2-, 1,4-, and 1,5-dimethyl-1,4-cyclohexadiene. The application of this method to 1,5-cyclooctadiene (**8**) and bicyclo[2.2.2]octa-2,5-diene (**7**) led to efficient syntheses of *endo*-tricyclo[4.3.0.0^{5,7}]nonan-2-ol (**38**) and *endo*-tetracyclo[4.3.0.0^{3,8}.0^{7,9}]nonan-2-ol (**39**). Although most of the lithiation–cyclizations of the bromocyclopropyl epoxides apparently occurred with net retention of configuration at the carbon bearing bromine, the *exo-anti*-bromocyclopropyl epoxide (**24**) from **7** cyclized to **39** with inversion of stereochemistry. Lithiation of a stereoisomeric mixture of the bromocyclopropyl epoxides (**31a–d**) from 1,5-hexadiene afforded the endo and exo isomers of both bicyclo[4.1.0]heptan-3-ol (**40a,b**) and bicyclo[3.1.0]hexane-2-methanol (**41a,b**).

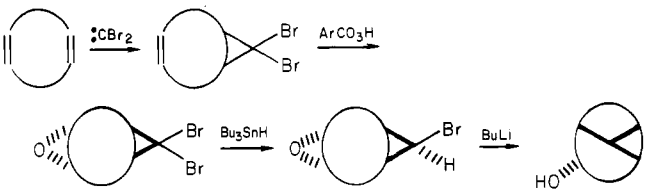
There has been considerable interest in the synthesis and reactions of homocyclopropylcarbinols such as *endo*-tricyclo[3.2.0.0^{2,7}]heptan-4-ol (**1**-OH) in connection with investigaitons of long-range cyclopropane participation in solvolytic rearrangements and under stable-ion conditions.[1] For example, ionization of **1**-X proceeds with cyclopropane participation and leads to a bishomo square-pyramidal type of nonclassical carbonium ion.[2] The exo isomer of tricyclic alcohol **1**-OH was prepared as a 73:27 mixture with its 3-isomer by hydroboration of tricyclo[3.2.0.0^{2,7}]hept-3-ene.[3] The endo alcohol **1** was obtained by subsequent



1 **2**

oxidation and reduction.[2] It occurred to us that homocyclopropylcarbinols of this type might be simply prepared by cyclization of lithiated cyclopropyl epoxides (**2**), an approach which would of necessity produce the requisite anti stereochemistry for cyclopropane participation. It is worthy of note that this cyclization involves the formation of a carbon–carbon bond exocyclic to a cyclopropane ring, and therefore the synthetic approach represents a violation of the rules proposed by Corey and co-workers[4] for analysis of bridged polycyclic structures.

Scheme I

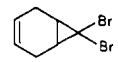
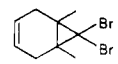
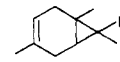
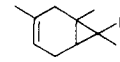
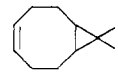
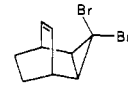
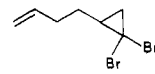


Although the synthetic utility of organolithium compounds in intermolecular reactions is widely appreciated, there have been relatively few reports of intramolecular

(1) (a) Masamune, S. *Pure Appl. Chem.* **1975**, *44*, 861–84. (b) Haywood-Farmer, J. *Chem. Rev.* **1974**, *74*, 315–50.
(2) Lustgarten, R. K. *J. Am. Chem. Soc.* **1972**, *94*, 7602–3.
(3) Lustgarten, R. K. *J. Am. Chem. Soc.* **1971**, *93*, 1275–7.
(4) Corey, E. J.; Howe, W. J.; Orf, H. W.; Pensak, D. A.; Petersson, G. *J. Am. Chem. Soc.* **1975**, *97*, 6116–24.

0022-3263/82/1947-3211$01.25/0

Table I. Dibromocyclopropanation of Dienes with Bromoform and Potassium *tert*-Butoxide in Pentane (Method A) or Aqueous Sodium Hydroxide and a Phase-Transfer Catalyst (Method B)

diene	method	dibromocyclopropane	yield, %
1,4-cyclohexadiene (3)	A	 10	44
1,2-dimethyl-1,4-cyclohexadiene (4)	A	 11	63
1,4-dimethyl-1,4-cyclohexadiene (5)	B	 12	53
1,5-dimethyl-1,4-cyclohexadiene (6)	A	 13	48
1,5-cyclooctadiene (8)	B	 14	47
bicyclo[2.2.2]octa-2,5-diene (7)	B	 15	57
1,5-hexadiene (9)	A	 16	50

reactions of these organometallics.[5] No doubt the expectation that the presence of electrophilic groups would be incompatible with methods used for generation of organolithium compounds has been a major deterrent to the use of this approach for ring formation. However, Parham[6] and others[5k,7] have demonstrated that halogen–metal exchange can be accomplished rapidly at low temperatures in the presence of such functionalities as acids, esters, amides, cyano and nitro groups, and other halogens. It therefore seemed likely that bromine–lithium exchange of bromocyclopropanes could be effected in the presence of an epoxide group.

As shown in Scheme I, the initial step in the proposed synthetic route involves the regiospecific addition of 1 equiv of dibromocarbene to a diene, followed by epoxidation of the remaining carbon–carbon double bond and partial reduction to the monobromocyclopropyl epoxide. Generation of the cyclopropyllithium by exchange with *n*-butyllithium sets the stage for intramolecular nucleophilic attack on epoxide and formation of a fused-ring alcohol containing two more rings than the starting diene. This reaction sequence would provide a relatively direct synthetic approach to a variety of homocyclopropylcarbinols.

Results and Discussion

The dienes required as starting materials for this investigation were prepared by literature methods or obtained from commercial suppliers. The Birch reduction of benzene and the appropriate xylene isomers according to the general method of Wibaut and Haak[8] afforded 1,4-cyclohexadiene (**3**, 51%), 1,2-dimethyl-1,4-cyclohexadiene (**4**, 65%), 1,4-dimethyl-1,4-cyclohexadiene (**5**, 72%), and 1,5-dimethyl-1,4-cyclohexadiene (**6**, 81%). Bicyclo[2.2.2]octa-2,5-diene (**7**) was prepared in 14% overall yield from 1,3-cyclohexadiene by a modification of the scheme described by Bird et al.[9] Commercially available 1,5-cyclooctadiene (**8**) and 1,5-hexadiene (**9**) were used without further purification.

The regioselective addition of dibromocarbene to the various dienes was carried out by two different methods. The method which gave the better yield is reported in each case in Table I. Dibromocarbene addition to 1,4-cyclohexadiene (**3**) was accomplished by the reaction of bromoform with potassium *tert*-butoxide in pentane at 0 °C according to the method of Farah and Gilbert[10] to give 7,7-dibromobicyclo[4.1.0]hept-3-ene (**10**) in 44% yield. Dibromocyclopropanes **11**, **13**, and **16** were prepared in a similar manner.

The second method for dibromocyclopropanation involved the reaction of bromoform with aqueous sodium hydroxide and cetyltrimethylammonium bromide (CTMA) as a phase-transfer catalyst according to the general me-

(5) (a) Stork, G.; Malhotra, S.; Thompson, H.; Uchibayashi, M. *J. Am. Chem. Soc.* **1965**, *87*, 1148–9. (b) House, H. O.; Riehl, J. J.; Pitt, C. G. *J. Org. Chem.* **1965**, *30*, 650–3. (c) Lansbury, P. T.; Sidler, J. D.; Caridi, F. J. "Abstracts of Papers", 152nd Meeting of the American Chemical Society, New York, NY, Sept 1966; American Chemical Society: Washington, DC, 1966; p 40U. (d) Sauers, R. R.; Parent, R. A.; Damle, S. B. *J. Am. Chem. Soc.* **1966**, *88*, 2257–62. (e) Sauers, R. R.; Hawthorne, R. M.; Dentz, B. I. *J. Org. Chem.* **1967**, *32*, 4071–2. (f) Pradhan, S. K.; Girijavallabhan, V. M. *Steroids* **1969**, *13*, 11–20. (g) Pradhan, S. K.; Radhakrishnan, T. V.; Subramanian, R. *J. Org. Chem.* **1976**, *41*, 1943–52. (h) Corbel, B.; Durst, T. *Ibid.* **1976**, *41*, 3648–50. (i) Coates, R. M.; Fretz, E. R. *Tetrahedron Lett.* **1977**, 1955–8. (j) Brewer, P. D.; Tagat, J.; Hergrueter, C. A.; Helquist, P. *Ibid.* **1977**, 4573–4. (k) Boatman, R. J.; Whitlock, B. J.; Whitlock, H. W. *J. Am. Chem. Soc.* **1977**, *99*, 4822–4. (l) Bradsher, C. K.; Reames, D. C. *J. Org. Chem.* **1978**, *43*, 3800–2. (m) Dhawan, K. L.; Gowland, B. D.; Durst, T. *Ibid.* **1980**, *45*, 922–4.

(6) (a) Parham, W. E.; Sayed, Y. A. *J. Org. Chem.* **1974**, *39*, 2051–3. (b) Parham, W. E.; Jones, L. D.; Sayed, Y. *Ibid.* **1975**, *40*, 2394–9. (c) Parham, W. E.; Jones, L. D.; Sayed, Y. A. *Ibid.* **1976**, *41*, 1184–6. (d) Parham, W. E.; Jones, L. D. *Ibid.* **1976**, *41*, 1187–91. (e) Parham, W. E.; Piccirilli, R. M. *Ibid.* **1976**, *41*, 1268–9. (f) Parham, W. E.; Egberg, D. C.; Sayed, Y. A.; Thraikill, R. W.; Keyser, G. E.; Neu, M.; Montgomery, W. C.; Jones, L. D. *Ibid.* **1976**, *41*, 2628–33. (g) Parham, W. E.; Jones, L. D. *Ibid.* **1976**, *41*, 2704–6.

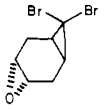
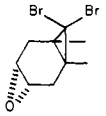
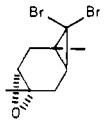
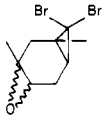
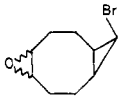
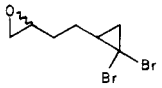
(7) Seebach, D.; Neumann, H. *Chem. Ber.* **1974**, *107*, 847–53.

(8) Wibaut, J. P.; Haak, F. A. *Recl. Trav. Chim. Pays-Bas* **1948**, *67*, 85–96.

(9) Bird, C. W.; Cookson, R. C.; Hudec, J.; Williams, R. O. *J. Chem. Soc.* **1963**, 410–21.

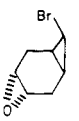
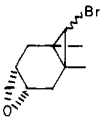
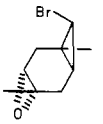
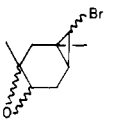
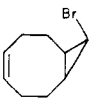
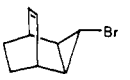
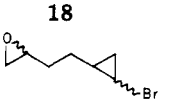
(10) Farah, B. S.; Gilbert, E. E. *J. Chem. Eng. Data* **1962**, *7*, 568–9.

Table II. Epoxidation of (Bromocyclopropyl)alkenes with *m*-Chloroperoxybenzoic Acid

alkene	epoxide	anti/syn ratio	yield, %
10	 **19**	100:0	87
11	 **20**	100:0	77
12	 **21**	100:0	64
13	 **22a,b**	83:17	74
17	 **23a,b**	50:50	77
18	 **24**	100:0	86
16	 **25a,b**	*a*	86

[a] The product is presumably an equimolar mixture of the two epoxide isomers.

Table III. Partial Reduction of Dibromocyclopropanes with Tri-*n*-butyltin Hydride

dibromide	monobromide	endo/exo ratio	yield, %
19	 **27**	100:0	82
20	 **28a,b**	75:25	73
21	 **29**	95:5[a]	93
22a, b	 **30a-d**	85:15	83
14	 **17**	100:0	52
15	 **18**	0:100	70
25a, b	 **31a-d**	60:40[b]	83

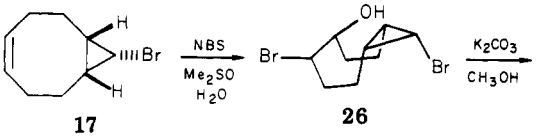
[a] A small amount of an unidentified compound was found to codistill with the product, presumably the exo isomer. [b] Ratio given is cis/trans.

thod of Joshi, Singh, and Pande.[11] Dibromocyclopropanes **12**, **14**, and **15** were prepared by this method.

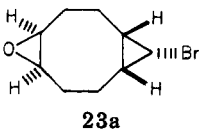
Addition of only one unit of dibromocarbene per diene was observed exclusively when 1 equiv of bromoform was used. Although no diadducts were isolated or detected, the formation of these products has been reported in the literature.[12]

Epoxidation of the remaining double bond of the bromocyclopropanes was carried out with *m*-chloroperoxybenzoic acid in dichloromethane. In general, epoxidation of the bicyclic olefins occurred from the less hindered face, resulting in predominant formation of the anti oxides. Apparently, the steric requirements of the bromocyclopropane ring are sufficient to block the attack of the epoxidizing agent on the syn face of the double bond. This directing effect is lost, however, when the distance between the cyclopropane ring and the double bond is increased, as is seen in the formation of epoxide **23** as a 50:50 mixture of anti and syn isomers. Although no proof that the predominant isomer possessed the anti configuration was obtained, Paquette and co-workers[13] have established the anti stereochemistry of dibromocyclopropyl epoxide **19** by X-ray crystallographic analysis. The results of the epoxidations are summarized in Table II.

Because the epoxidation of alkene **17** with *m*-chloroperoxybenzoic acid is nonstereospecific, another method for formation of the epoxide ring was needed. Treatment of alkene **17** with *N*-bromosuccinimide in dimethyl sulf-



17 **26**



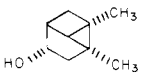
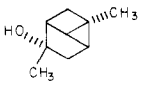
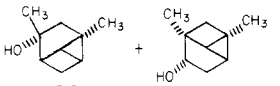
23a

oxide followed by base-induced cyclization of bromohydrin **26** gave a single epoxide (by GC) in 76% yield. If it is assumed that cyclooctene **17** exists predominantly in a tub conformation with the cyclopropane ring exo, attack of bromine on the double bond should occur from the exo direction and produce a trans bromohydrin in which the new bromo group is cis to the three-membered ring (i.e., **26**).

Partial reduction of the *gem*-dibromocyclopropanes was accomplished by reaction with tri-*n*-butyltin hydride[14]

(11) Joshi, G. C.; Singh, N.; Pande, L. M. *Tetrahedron Lett.* **1972**, 1461–4.
(12) Winstein, S.; Sonnenberg, J. *J. Am. Chem. Soc.* **1961**, *83*, 3235–44.
(13) Paquette, L. A.; Fristad, W. E.; Schuman, C. A.; Beno, M. A.; Christoph, G. G. *J. Am. Chem. Soc.* **1979**, *101*, 4645–55.

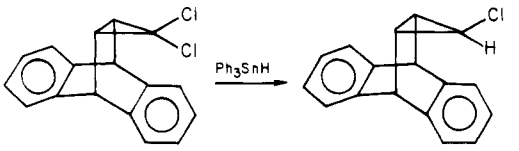
Table IV. Cyclization of Bromocyclopropyl Epoxides with *n*-Butyllithium in Tetrahydrofuran or Hexane[a]

bromocyclopropyl epoxide	alcohol	yield, %
27	 1	69
28a	 34	84
29	 35	59
30a-d	 36 + 37 5:1	56[b]
23a	 38	50
24	 39	84

[a] Cyclization of **24** was carried out in hexane. All others were done in tetrahydrofuran. Cyclizations of **23a** and **24** were carried out at room temperature. All others were done at 0 °C. [b] Yield is based on all four isomers of bromocyclopropyl epoxide. The yield is 80% when based on the *endo*-bromo *anti*-oxide isomer.

according to the general procedure of Seyferth and co-workers.[15] The results are summarized in Table III.

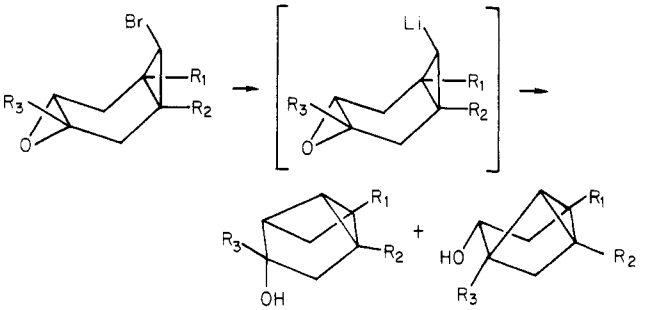
Tin hydride reagents are known to have a tendency to remove the less hindered halogen from *gem*-dihalocyclopropanes.[15] If the intermediate cyclopropyl radical inverts rapidly, however, the stereochemistry is determined only in the last step, i.e., hydrogen atom transfer. Jefford and co-workers[16] have shown that the reduction of cyclopropyl halides is best explained by intervention of a cyclopropyl radical which tends to retain its configuration but may invert if compelled to do so by virtue of intramolecular nonbonded interactions. In the present study, it is presumed that attack by the tin hydride reagent results in removal of the exo bromine atom (trans bromine in the acyclic case). The formation of some *exo*-bromocyclopropyl epoxide can be explained by equilibration of the radical formed due to steric crowding of the endo bromine and capture by hydrogen atom transfer to the more stable radical. This explanation finds support in the literature. Cristol, Sequeira, and DePuy[17] have observed that triphenyltin hydride transformed dichloride **32** to the monochloride **33** without formation of the epimer of **33**. This proposed inversion accounts for the exclusive formation of *exo*-bromocyclopropane **18**.



32 **33**

The stereochemistry of the cyclopropane ring was determined from the coupling constants between vicinal cyclopropane hydrogens in the proton NMR spectra. The Karplus equations predict a cis coupling of 8.2 Hz and a trans coupling of 3.8–4.3 Hz.[18] A number of workers[19] have reported coupling constants for substituted cyclopropanes which are in good agreement with the theoretical prediction. In the present study, cis coupling constants of 7–9 Hz and trans coupling constants of 2–5 Hz were observed.

The key step in the synthesis, the intramolecular nucleophilic attack of the cyclopropyllithium reagent on the epoxide, was effected by exchange of the monobromocyclopropane with *n*-butyllithium in tetrahydrofuran. Cyclization then led to the expected tri- and tetracyclic alcohols. The results are summarized in Table IV. An attempt was made to generate the cyclopropyllithium reagent in several cases by reaction of the bromocyclopropane with lithium 4,4′-di-*tert*-butylbiphenyl according to the method of Freeman and Hutchinson.[20] The same cyclized alcohols were obtained but in very poor yields.



The question of the regiochemistry of the intramolecular attack arises in the cyclization of bromo epoxides **29** and **30**, in which the epoxide is unsymmetrically substituted. As expected, the major product from the cyclization of bromo epoxide **30** was tertiary alcohol **36**, resulting from attack at the less hindered oxirane carbon. The isomeric secondary alcohol **37** was formed as a minor product. Similarly, the major product from the cyclization of bromo epoxide **29** was tertiary alcohol **35**. A small amount of a mixture of compounds was also isolated by column chromatography. NMR spectral data of the mixture (four major components by GC) are consistent with the presence of the isomeric secondary alcohol resulting from attack at the more hindered side of the epoxide. Absorptions in the olefinic region suggest the possible presence of allylic alcohols resulting from base-induced β-elimination.

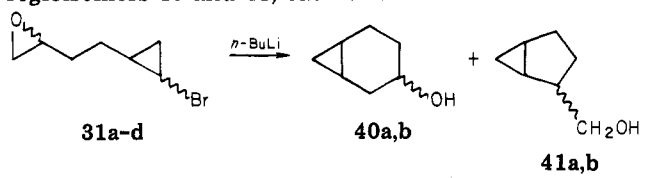
The mechanism of the formation of alcohol **39** from bromo epoxide **24** deserves comment. Since the bromine in **24** is exo, configurational inversion of the cyclopropyllithium must occur prior to or during cyclization. To our knowledge, there have been no examples of inversions of a cyclopropyllithium compound reported in the literature. Dewar and Harris[21] and Walborsky[22] have re-

(14) van der Kerk, G. J. M.; Noltes, J. G.; Luijten, J. G. A. *J. Appl. Chem.* **1957**, *7*, 366–9.
(15) Seyferth, D.; Yamazaki, H.; Alleston, D. L. *J. Org. Chem.* **1963**, *28*, 703–6.
(16) Jefford, C. W.; Burger, U.; Laffer, M. H.; Kabengele, T. *Tetrahedron Lett.* **1973**, 2483–6.
(17) Cristol, S. J.; Sequeira, R. M.; DePuy, C. H. *J. Am. Chem. Soc.* **1965**, *87*, 4007–8.
(18) Patel, D. J.; Howden, M. E. H.; Roberts, J. D. *J. Am. Chem. Soc.* **1963**, *85*, 3218–23.
(19) (a) Graham, J. D.; Rogers, M. T. *J. Am. Chem. Soc.* **1962**, *84*, 2249–52. (b) Williamson, K. L.; Lanford, C. A.; Nicholson, C. R. *Ibid.* **1964**, *86*, 762–5. (c) Katz, T. J.; Garratt, P. J. *Ibid.* **1964**, *86*, 5194–202.
(20) Freeman, P. K.; Hutchinson, L. L. *J. Org. Chem.* **1980**, *45*, 1924–30.

ported that although the stereochemistry of cyclopropyllithium compounds generated from lithium metal was lost, the cyclopropyllithium compounds were in fact configurationally stable when formed by exchange with *n*-butyllithium. It was thus concluded that once the cyclopropyllithium reagents are formed, no inversion takes place. Considering the long reaction time involved in the conversion of bromo epoxide **24** to alcohol **39**, it is not unreasonable to propose a slow equilibration of the cyclopropyllithium, followed by rapid cyclization of the *syn*-cyclopropyllithium to **39**-OLi. This slow equilibration is perhaps assisted by the excess butyllithium present which proved to be necessary for the reaction to occur.

Another mechanism could involve the electrophilic attack of the epoxide on the backside of the cyclopropyllithium, i.e., electrophilic substitution with inversion of configuration. The effect of the excess butyllithium (or lithium halide) in this case could be to complex with the oxygen of the epoxide and thereby increase the electrophilicity of the epoxide carbons. Electrophilic attack on alkyllithium compounds with inversion of stereochemistry has been postulated in the literature.[23]

Finally, the cyclization of bromo epoxide **31** was attempted. Since the *cis*- and *trans*-bromocyclopropanes could not be separated, the mixture of isomers was treated with *n*-butyllithium. The product was a 60:40 mixture of regioisomers **40** and **41**, each of which was a mixture of

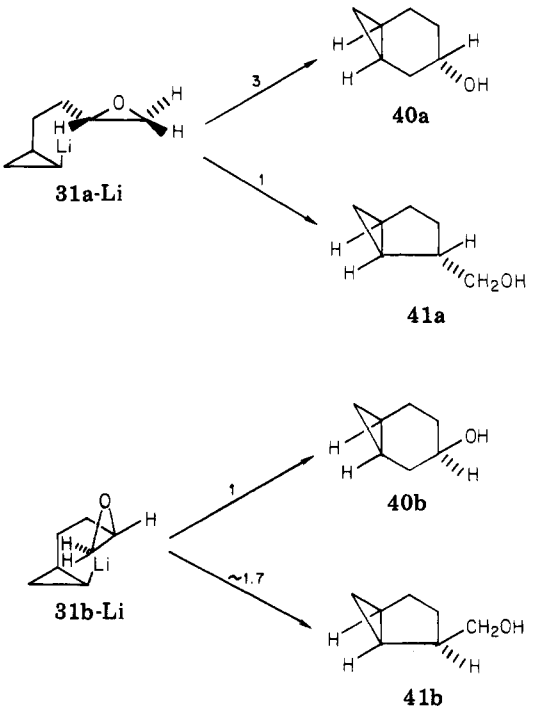


31a-d **40a,b** **41a,b**

60:40

endo and exo alcohols. The identity of the secondary bicyclic alcohols **40a** and **40b** was established by comparison of their NMR and IR spectra and GC retention times with those of samples prepared by literature procedures. *exo*-Bicyclo[4.1.0]heptan-3-ol (**40a**) was prepared by reductive opening of the epoxide of bicyclo[4.1.0]-hept-3-ene *anti*-oxide[13] according to the general procedure of Brown and co-workers.[24a] *endo*-Bicyclo[4.1.0]heptan-3-ol (**40b**) was prepared by Simmons–Smith reaction of 3-cyclohexenol[24b] according to the procedure of Hanack and Krause.[24c] The structures of primary alcohols **41a** and **41b** were inferred from their spectral characteristics. The ratios of **40a**/**40b** and **41a**/**41b**, were estimated from both integration of the ^{1}H NMR spectra and relative line intensities of the ^{13}C NMR spectra of each mixture. The results of this analysis are shown in Scheme II. The major isomer from cyclization of **31a**-Li is the secondary alcohol **40a**, resulting from attack at the less hindered oxirane carbon, with attack at the more hindered site giving rise to the minor isomer, primary alcohol **41a**. On the other hand, it appears that this natural preference is overshadowed by a more favorable orbital overlap in **31b**-Li, giving rise to a preference for attack at the tertiary carbon and predominance of primary alcohol **41b**.

Scheme II



31a-Li **40a** **41a**

31b-Li **40b** **41b**

In summary, this research has demonstrated that polycyclic homocyclopropylcarbinols may be readily prepared by lithiation of bromocyclopropyl epoxides with *n*-butyllithium followed by intramolecular attack of the cyclopropyllithium group onto the epoxide. The bromocyclopropyl epoxides were obtained in three steps from diene precursors via dibromocyclopropanation, epoxidation, and tin hydride reduction. The overall yields of the homocyclopropylcarbinols from the dienes ranged from 9 to 29% for the six cases examined. In general it appears that the endo,anti stereochemistry of the bromine and epoxide groups is a prerequisite for rapid, efficient cyclization. However, one bromocyclopropyl epoxide having an *exo*-bromine stereochemistry underwent efficient, albeit slow, ring closure with net inversion of configuration at carbon bearing bromine (**24** → **39**).

Experimental Section

Melting points were determined in open capillary tubes, unless noted otherwise, by using a Thomas-Hoover melting point apparatus and are not corrected. All boiling points are uncorrected. Proton nuclear magnetic resonance (^{1}H NMR) spectra were obtained with either a Varian EM-390 (90 MHz) or a Varian HR 220 (220 MHz) spectrometer. The frequency was 90 MHz unless specified otherwise. Carbon-13 nuclear magnetic resonance (^{13}C NMR) spectra were obtained with a JEOL FX60 (15 MHz) spectrometer. All infrared (IR) spectra were obtained with a Perkin-Elmer 137 sodium chloride spectrophotometer. Microanalyses were performed by J. Nemeth and associates in the University of Illinois Microanalytical Laboratory. Analytical gas chromatography (GC) was performed on a Varian Model 3700 gas chromatograph, and preparative GC was performed on a Varian Aerograph 90-P gas chromatograph by using the following columns: (A) 1.8 m × 6.4 mm, 3% OV-17 on 100/120-mesh Chromosorb Q, (B) 3.6 m × 6.4 mm, 3% OV-17 on 100/120-mesh Chromosorb Q, (C) 2.7 m × 9.5 mm, 20% OV-17 on 60/80-mesh Chromosorb P, (D) 1.5 m × 9.5 mm, 20% SE-30 on 60/80-mesh Chromosorb W, (E) 2.4 m × 9.5 mm, 20% Carbowax 20M on 60/80-mesh Chromosorb P.

All reagents and solvents were reagent grade and used without further purification unless otherwise specified. Technical grade hexane and ethyl acetate used for column chromatography were distilled prior to use. Tetrahydrofuran (THF) was distilled from the sodium ketyl of benzophenone. Hexane was dried over 4-Å

(21) Dewar, M. J. S.; Harris, J. M. *J. Am. Chem. Soc.* **1969**, *91*, 3652–3.
(22) Walborsky, H. M.; Aronoff, M. S. *J. Organomet. Chem* **1965**, *4*, 418–20.
(23) (a) Applequist, D. E.; Peterson, A. H. *J. Am. Chem. Soc.* **1961**, *83*, 862–5. (b) Applequist, D. E.; Chmurny, G. N. *Ibid.* **1967**, *89*, 875–80. (c) Glaze, W. H.; Selman, C. M.; Ball, A. L.; Bray, L. E. *J. Org. Chem.* **1969**, *34*, 641–4.
(24) (a) Brown, H. C.; Ikegami, S.; Kawakami, J. H. *J. Org. Chem.* **1970**, *35*, 3243–5. (b) Chan, J. H.-H.; Rickborn, B. *J. Am. Chem. Soc.* **1968**, *90*, 6406–11. (c) Hanack, M.; Krause, P. C. *Justus Liebigs Ann. Chem.* **1972**, *760*, 17–26.

molecular sieves and decanted before use. *n*-Butyllithium was obtained as a commercially prepared solution in hexane and was titrated prior to use.[25] Commercially available 1,5-cyclooctadiene (8) and 1,5-hexadiene (9) were used without further purification.

1,4-Cyclohexadiene (3). General Procedure for Birch Reduction of Substituted Benzenes. The method of Wibaut and Haak[8] was used with some modification.

Approximately 700 mL of ammonia was condensed and vigorously stirred at −78 °C as 87.8 g (1.13 mol) of benzene was added dropwise. After the addition was complete, 78.0 g (3.39 mol) of sodium was added as small pieces, after which 161 g (3.50 mol) of precooled absolute ethanol was added dropwise. After 3 h at −78 °C, the cooling bath was removed and the ammonia was allowed to evaporate overnight. Water was carefully added to the reaction mixture. The organic layer was removed, washed with water and dilute hydrochloric acid, and dried ($MgSO_4$). Distillation gave 46.5 g (51%) of 1,4-cyclohexadiene (3) as a colorless liquid, bp 87–88 °C.

The following dienes were prepared according to the preceding procedure.

1,2-Dimethyl-1,4-cyclohexadiene (4): yield, 106 g (65%); bp 36.5–37.5 °C (13 mm).

1,4-Dimethyl-1,4-cyclohexadiene (5): yield, 117 g (72%); bp 33–35 °C (12 mm).

1,5-Dimethyl-1,4-cyclohexadiene (6): yield, 88 g (81%); 34–35 °C (13 mm).

Synthesis of Bicyclo[2.2.2]octa-2,5-diene (7). *endo*-Bicyclo[2.2.2]oct-2-ene-5-carbonyl chloride (42) was prepared by the procedure of Bird et al.:[9] 66% yield (lit.[9] 77% yield); bp 98–101 °C (20 mm) [lit.[9] bp 99–102 °C (17 mm)]. **Bicyclo[2.2.2]oct-2-en-5-amine (43).** A solution of 50.0 g (0.293 mol) of acid chloride 42 and 40.3 g (0.35 mol) of trimethylsilyl azide[26] in 100 mL of carbon tetrachloride was stirred and heated gently under a nitrogen atmosphere until nitrogen evolution was observed. The mixture was then cooled in a water bath until the exothermic reaction had subsided. The mixture was heated to 80 °C, and after 1 h the trimethylsilyl chloride and carbon tetrachloride were evaporated at atmospheric pressure. The residue was added dropwise to 175 mL of refluxing 20% hydrochloric acid over a period of 1 h. After an additional hour at reflux, the reaction mixture was cooled and made strongly basic by the addition of 50% potassium hydroxide solution. The organic product was extracted with three portions of ether, the solution was dried ($MgSO_4$), and the solvent was evaporated under reduced pressure. Distillation of the residual liquid gave 28.0 g (78%) of amine 43 as a colorless oily solid, bp 90–95 °C (25 mm) [lit.[9] bp 98–101 °C (10 mm)]. An attempt to prepare amine 43 by the procedure of Bird et al.[9] afforded product in 26% yield. ***N,N*-Dimethylbicyclo[2.2.2]oct-2-en-5-amine (44)** was prepared by the procedure of Bird et al.:[9] 58% yield (lit.[9] 70% yield); bp 80–81 °C (15 mm) [lit.[9] bp 78–82 °C (12 mm)]. **Bicyclo[2.2.2]octa-2,5-diene (7)** was prepared by the procedure of Bird et al.:[9] 45% yield (lit.[9] 75.5% yield); bp 70–80 °C (120 mm) [lit.[9] mp 51–5 °C]. The IR and NMR spectral data of the product correspond to those reported in the literature.[27]

7,7-Dibromobicyclo[4.1.0]hept-3-ene (10). General Procedure for Dibromocyclopropanation with Bromoform and Potassium *tert*-Butoxide. The method of Winstein[12] was used with some modification.

A mixture of 20.5 g (0.256 mol) of 1,4-cyclohexadiene (3) and 50.4 g (0.449 mol) of potassium *tert*-butoxide in 250 mL of pentane was stirred and cooled at 0 °C as 64.9 g (0.257 mol) of bromoform was added over 75 min. After an additional 1 h at 0 °C and 30 min at room temperature, the mixture was poured into water. The organic product was extracted with three portions of pentane, the solution was dried ($MgSO_4$), and the solvent was evaporated under reduced pressure. Distillation of the residual liquid through a 15-cm Vigreux column gave 34.2 g (53% crude yield) of a colorless liquid, bp 53–58 °C (0.2 mm). The distillate was cooled in ice, and white crystals precipitated. The solid was melted, a few drops of absolute ethanol were added, and the mixture was allowed to cool to room temperature. Crystallization gave 28.3 g (44%) of dibromocyclopropane 10 as colorless crystals: mp 37.5–38.0 °C (lit.[12] mp 37.8–38.8 °C); IR (Nujol) 2890, 1660, 1420, 1325, 1120, 1055, 1000, 940, 818, 736 cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.8–2.0 (m, 2 H, two bridgehead H), 2.05 (d, 2 H, J = 19 Hz, two allylic H), 2.51 (dm, 2 H, J = 19 Hz, two allylic H), 5.44 (s, 2 H, two vinyl H). Anal. Calcd for $C_7H_8Br_2$: C, 33.37; H, 3.20; Br, 63.43. Found: C, 33.12; H, 2.95; Br, 63.37.

The following dibromocyclopropanes were prepared by the same procedure used for dibromocarbene addition to 1,4-cyclohexadiene (3) above.

7,7-Dibromo-1,6-dimethylbicyclo[4.1.0]hept-3-ene (11): yield, 86.7 g (63%); mp 102–104 °C (lit.[13] mp 105–106 °C). The IR and NMR spectral data of the product correspond to those reported by Paquette and co-workers.[13]

7,7-Dibromo-1,3-dimethylbicyclo[4.1.0]hept-3-ene (13): yield, 85.0 g (48%); bp 73–75 °C (0.35 mm) [lit.[28] bp 91–92 °C (0.8 mm)]. The IR and NMR spectral data of the product correspond to those reported by Paquette and co-workers.[28]

1,1-Dibromo-2-(3-butenyl)cyclopropane (16): yield, 38.1 g (50%); bp 41–42 °C (0.3 mm) [lit.[29] bp 78–79 °C (8 mm)]; IR spectral data of the product correspond to those reported by Skattebol;[29] ^1H NMR ($CDCl_3$) δ 1.1–1.9 (m, 5 H, 3 ring H and side chain CH_2), 2.25 (dt, 2 H, J = 7, 6 Hz, 2 allylic H), 4.96 (apparent d, 1 H, J = 2 Hz, 1 terminal vinyl H), 5.07 (apparent dd, 1 H, J = 10, 1 Hz, 1 terminal vinyl H), 5.83 (apparent ddt, 1 H, J = 20, 10, 7 Hz, $H_2C{=}CH$). Anal. Calcd for $C_7H_{10}Br_2$: C, 33.11; H, 3.97; Br, 62.93. Found: C, 33.02; H, 3.78; Br, 63.17.

7,7-Dibromo-1,4-dimethylbicyclo[4.1.0]hept-3-ene (12). General Procedure for Phase-Transfer-Catalyzed Dibromocyclopropanation. The method of Joshi, Singh, and Pande[11] was used.

A mixture of 54.1 g (0.50 mol) of 1,4-dimethyl-1,4-cyclohexadiene (5), 126.4 g (0.50 mol) of bromoform, and 1.8 g (5 mmol) of cetyltrimethylammonium bromide was stirred and heated at 50 °C as a solution of 154 g (3.85 mol) of sodium hydroxide in 310 mL of water was added over a period of 45 min. The mixture was stirred at 50 °C for an additional 2 h, cooled to room temperature, diluted with ice–water, and neutralized with 10% sulfuric acid. The organic product was extracted with four portions of ether, the solution was dried ($MgSO_4$), and the solvent was evaporated under reduced pressure. Distillation of the residual liquid through a 15-cm Vigreux column gave 74.0 g (53%) of dibromocyclopropane 12 as a colorless liquid: bp 80–81 °C (0.4 mm) [lit.[28] bp 79–80 °C (0.5 mm)]. The IR and NMR spectal data of the product correspond to those reported by Paquette and co-workers.[28] Anal. Calcd for $C_9H_{12}Br_2$: C, 38.61; H, 4.32; Br, 57.07. Found: C, 38.58; H, 4.30; Br, 56.98.

The following dibromocyclopropanes were prepared by the same procedure used for dibromocarbene addition to 1,4-dimethyl-1,4-cyclohexadiene (5) above.

9,9-Dibromobicyclo[6.1.0]non-4-ene (14): yield, 12.2 g (47%); bp 93–94 °C (0.6 mm) [lit.[10] bp 135 °C (12 mm)]; IR (film) 3000, 2900, 1660, 1480, 1440, 1200, 1180, 1100, 1000, 955, 810, 750, 710 cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.74 (apparent d, 2 H, J = 3 Hz, 2 bridgehead H), 1.8–2.6 (m, 8 H, 4 CH_2), 5.50 (apparent t, 2 H, J = 4 Hz, 2 vinyl H). Anal. Calcd for $C_9H_{12}Br_2$: C, 38.61; H, 4.32; Br, 57.07. Found: C, 38.65; H, 4.35; Br, 56.88.

***endo*-3,3-Dibromotricyclo[3.2.2.0^{2,4}]non-6-ene (15)**: yield, 5.5 g (57%); IR (film) 3060, 2950, 2850 cm^{-1}; ^1H NMR (CCl_4) δ 1.1–1.6 (m, 4 H, 2 CH_2), 1.90 (t, 2 H, J = 2 Hz, 2 cyclopropyl H), 3.13 (m, 2 H, 2 bridgehead H), 5.93 (dd, 2 H, J = 5, 3 Hz, 2 vinyl H).

7,7-Dibromobicyclo[4.1.0]hept-3-ene *anti*-Oxide (19). General Procedure for Epoxidation with *m*-Chloroperoxybenzoic Acid. The procedure described by Paquette and coworkers[13] was used. A mixture of 20.0 g (79.4 mmol) of dibromocyclopropane 10 and 12.4 g (148 mmol) of sodium bicarbonate in 300 mL of dichloromethane was stirred and cooled

(25) Watson, S. C.; Eastham, J. F. *J. Organomet. Chem.* **1967**, *9*, 165–8.
(26) (a) Washburne, S. S.; Peterson, W. R. *Synth. Commun.* **1972**, *2*, 227–30. (b) Washburne, S. S.; Peterson, W. R. *J. Organomet. Chem.* **1971**, *33*, 153–6.
(27) (a) Volgen, H. C.; Gaasbeck, M.; Hogeveen, H.; Vriege, K. *Inorg. Chim. Acta* **1969**, *3*, 145–50. (b) Tori, K.; Takano, Y.; Kitahonoki, K. *Chem. Ber.* **1964**, *97*, 2798–815.
(28) Bischof, P.; Gleiter, R.; Taylor, R. T.; Browne, A. R.; Paquette, L. A. *J. Org. Chem.* **1978**, *43*, 2391–6.
(29) Skattebol, L. *J. Org. Chem.* **1964**, *29*, 2951–6.

at 0 °C as a solution of 20.5 g (100 mmol) of 80–90% *m*-chloroperoxybenzoic acid in 300 mL of dichloromethane was added over a period of 2 h. The mixture was stirred at 0 °C for an additional 8 h, warmed to room temperature, and stirred overnight. The mixture was washed with water, 20% sodium bisulfite solution, 10% sodium bicarbonate solution, and saturated sodium chloride solution. The solution was dried ($MgSO_4$), and the solvent was evaporated under reduced pressure. Distillation of the residual liquid through a 15-cm Vigreux column gave 18.6 g (87%) of a colorless liquid, bp 74–76 °C (0.15 mm), which solidified upon cooling in ice. Recrystallization from hexane gave dibromocyclopropyl epoxide **19** as colorless crystals: mp 50–51 °C (lit.[13] mp 50–51 °C); IR (Nujol) 2850, 1440, 1360, 1055, 1010, 925, 795, 725 cm^{-1}. The NMR spectral data of the product correspond to those reported by Paquette and co-workers.[13]

The following bromocyclopropyl epoxides were prepared according to the preceding procedure for the preparation of **19**.

7,7-Dibromo-1,6-dimethylbicyclo[4.1.0]hept-3-ene *anti*-Oxide (20): yield, 18.1 g (77%); mp 91–94 °C (lit.[13] mp 90–94 °C). The IR and NMR spectal data of the product correspond to those reported by Paquette and co-workers.[13]

7,7-Dibromo-1,4-dimethylbicyclo[4.10]hept-3-ene *anti*-Oxide (21): yield, 10.2 g (64%); bp 81–82 °C (0.25 mm); IR (film) 2950, 2900, 1450, 1420, 1375, 1210, 1100, 1020, 930, 835, 765 cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.24 (s, 3 H, CH_3), 1.34 (s, 3 H, CH_3), 1.34 (dd, 1 H, J = 8, 2 Hz, bridgehead H), 1.70 (dd, 1 H, J = 15, 2 Hz, 1 H of CH_2), 2.12 (d, 2 H, J = 2 Hz, CH_2), 2.27 (dd, 1 H, J = 15, 8 Hz, 1 H of CH_2), 2.72 (t, 1 H, J = 2 Hz, epoxide H). Anal. Calcd for $C_9H_{12}Br_2O$: C, 36.52; H, 4.09; Br, 53.99. Found: C, 36.78; H, 4.01; Br, 54.18.

7,7-Dibromo-1,3-dimethylbicyclo[4.1.0]hept-3-ene *anti*- and *syn*-Oxides (22a,b): yield, 11.0 g (74%); bp 71–74 °C (0.15 mm). Analysis by GC (column A, 110 °C, 40 mL/min, t_R = 8.0 and 6.4 min) indicated the product was an 83:17 mixture of anti and syn isomers, respectively. The spectral properties of the product are as follows: IR (film) 2950, 1455, 1435, 1380, 1215, 1105, 1030, 985, 925, 835, 760 cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.30 (s, 3 H, CH_3), 1.42 (s, 3 H, CH_3), 1.3–2.1 (m, 2 H, bridgehead H and 1 H of CH_2), 2.07 (s, 2 H, CH_2), 2.51 (dd, 1 H, J = 17, 9 Hz, 1 H of CH_2), 2.88 (br s, 1 H, epoxide H). Anal. Calcd for $C_9H_{12}Br_2O$: C, 36.52; H, 4.09; Br, 53.99. Found: C, 36.37; H, 4.01; Br, 54.16.

***endo*-9-Bromobicyclo[6.1.0]non-4-ene *anti*- and *syn*-Oxides (23a,b)**. Reaction in ether at room temperature for 21 h gave 0.83 g (77%) of monobromocyclopropyl epoxide **23** as a colorless liquid. Analysis by GC (column E, 170 °C) indicated the product was a 50:50 mixture of anti and syn isomers.

1,1-Dibromo-2-(3-butenyl)cyclopropane Oxide (25a,b): yield, 36.4 g (86%); bp 76–77 °C (0.3 mm); IR (film) 2950, 2900, 2850, 1480, 1440, 1260, 1115, 1045, 915, 840, 735 cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.23 (apparent t, 1 H, J = 5 Hz, cyclopropane H), 1.73 (br s, 6 H), 2.48 (dd, 1 H, J = 3 Hz, epoxide H), 2.78 (t, 1 H, J = 4.5 Hz, epoxide H), 2.98 (m, 1 H, epoxide H). Anal. Calcd for $C_7H_{10}Br_2O$: C, 31.14; H, 3.73; Br, 59.20. Found: C, 31.24; H, 3.56; Br, 59.27.

***endo*-9-Bromobicyclo[6.1.0]non-4-ene *anti*-Oxide (23a)**. A solution of 5.9 g (29 mmol) of monobromocyclopropane **17**, 10.7 g (60 mmol) of *N*-bromosuccinimide, and 1.1 mL (60 mmol) of water in 88 mL of dimethyl sulfoxide was stirred and cooled at 10 °C. After 30 min at 10 °C, the solution was diluted with 5% sodium bicarbonate solution. The organic product was extracted with three portions of ether and the ethereal solution was dried ($MgSO_4$). Evaporation of the solvent under reduced pressure gave 9.1 g (100% crude yield) of bromohydrin **26** as a yellow oil. A suspension of 13.5 g (98 mmol) of potassium carbonate in a solution of the bromohydrin in 350 mL of methanol was stirred at 25 °C for 1 h under a nitrogen atmosphere. Water (200 mL) was added and the organic product was extracted with three portions of ether. The solution was washed with three portions of water, dried ($MgSO_4$), and evaporated under reduced pressure. Recrystallization of the white solid from hexane gave 4.8 g (76%) of monobromocyclopropyl epoxide **23a** as white crystals: mp 72–74 °C. IR (Nujol) 1285, 1255, 1195, 1110, 1070, 1025, 975, 870, 775 cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.0–1.5 (m, 6 H, 2 CH_2 and 2 bridgehead H), 1.8–2.6 (m, 4 H, 2 CH_2), 3.0 (m, 2 H, 2 epoxide H), 3.20 (t, 1 H, J = 7 Hz, CHBr). Anal. Calcd for $C_9H_{13}BrO$: C, 49.79; H, 6.04; Br, 36.80. Found: C, 49.53; H, 5.97; Br, 36.67.

***endo*-3-Bromo-*endo*-tricyclo[3.2.2.0^{2,4}]non-6-ene *anti*-Oxide (24)**. A solution of 7.8 g (36 mmol) of monobromocyclopropane **18** in 90 mL of chloroform was stirred and cooled at 0 °C as 26.2 g (0.152 mol) of *m*-chloroperoxybenzoic acid was added in three equal portions under a nitrogen atmosphere. The cooling bath was removed, and after 3 h at room temperature, the reaction mixture was diluted with 500 mL of ether. The solution was washed with three portions of 10% sodium sulfite solution, three portions of 2 N sodium hydroxide solution, and two portions of water. The solution was dried ($MgSO_4$), and the solvent was evaporated under reduced pressure. Recrystallization of the resulting solid from methanol gave 7.28 g (86%) of monobromocyclopropyl epoxide **24** as a white solid: mp 60–60.5 °C; IR (Nujol) 1405, 1330, 1290, 1210, 1195, 1170, 1155, 1070, 1015, 935, 855, 805, 725 cm^{-1}; ^1H NMR (CCl_4) δ 1.1–1.8 (m, 6 H, 2 CH_2 and 2 cyclopropyl H), 2.4–2.7 (m, 2 H, 2 bridgehead H), 2.8–3.0 (m, 2 H, 2 epoxide H), 3.18 (t, 1 H, J = 2 Hz, CHBr). Anal. Calcd for $C_9H_{11}BrO$: C, 50.26; H, 5.15; Br, 37.15. Found: C, 50.28; H, 5.23; Br, 37.02.

***endo*-7-Bromobicyclo[4.1.0]hept-3-ene *anti*-Oxide (27). General Procedure for Partial Reduction of *gem*-Dibromocyclopropanes with Tri-*n*-butyltin Hydride.** The procedure described by Seyferth and co-workers[15] was used with some modification. A solution of 23.7 g (88.4 mmol) of dibromocyclopropyl epoxide **19** in 250 mL of toluene was stirred and cooled at −10 °C as 25.7 g (88.3 mmol) of tri-*n*-butyltin hydride[14] was added dropwise under nitrogen. After 4 h at −10 °C, the solvent was evaporated under reduced pressure. Distillation of the residual liquid through a 15-cm Vigreux column gave 13.7 g (82%) of a colorless liquid, bp 54–56 °C (0.2 mm), which solidified upon cooling in ice. Recrystallization from hexane gave monobromocyclopropyl epoxide **27** as colorless needles: mp 50–51.5 °C; IR (Nujol) 1425, 1255, 1075, 1015, 915, 800, 730 cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.11 (apparent t, 2 H, J = 8 Hz, 2 bridgehead H), 1.82 (apparent d, 2 H, J = 16 Hz, 1 H each of two CH_2), 2.42 (apparent dd, 2 H, J = 16, 7 Hz, 1 H each of two CH_2), 3.10 (br s, 2 H, 2 epoxide H), 3.31 (t, 1 H, J = 8 Hz, CHBr). Anal. Calcd for C_7H_9BrO: C, 44.47; H, 4.80; Br, 42.27. Found: C, 44.56; H, 4.83; Br, 42.26.

The following monobromocyclopropanes were prepared according to the preceding procedure for the preparation of **27** with the deviations noted.

***endo*- and *exo*-7-Bromo-1,6-dimethylbicyclo[4.1.0]hept-3-ene *anti*-Oxide (28a,b)**. Reaction in benzene at 50 °C gave 9.5 g (73%) of a colorless liquid, bp 44–46 °C (0.1 mm). Analysis by ^1H NMR indicated the product was a 75:25 mixture of *endo*- and *exo*-bromo isomers. Recrystallization from pentane of the solid formed on allowing the mixture to stand at −25 °C gave 4.0 g of *endo*-bromocyclopropyl epoxide **28a** as colorless crystals, mp 58.0–59.0 °C. The mother liquor was a 50:50 mixture of endo and exo isomers. The spectral data for the endo isomer **28a** are as follows: IR (Nujol) 1470, 1380, 1340, 1270, 1075, 1030, 1020, 960, 890, 870, 810 cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.16 (s, 6 H, 2 CH_3), 2.06 (d, 4 H, J = 1 Hz, 2 CH_2), 2.72 (s, 1 H, CHBr), 3.06 (d, 2 H, J = 1 Hz, 2 epoxide H). Anal. Calcd for $C_9H_{13}BrO$: C, 49.79; H, 6.04; Br, 36.80. Found: C, 49.56; H, 5.97; Br, 36.73. The spectral data for the exo isomer **28b** are as follows: IR (film) 1430, 1380, 1260, 1090, 1010, 900, 810 cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.11 (s, 6 H, 2 CH_3), 2.0 (m, 4 H, 2 CH_2), 2.64 (s, 1 H, CHBr), 3.0 (br s, 2 H, 2 epoxide H).

***endo*-7-Bromo-1,4-dimethylbicyclo[4.1.0]hept-3-ene *anti*-Oxide (29)**. Reaction in benzene at 0 °C for 4 h and then at room temperature for 19 h gave 6.1 g (93%) of monobromocyclopropyl epoxide **29** as a colorless liquid, bp 44–45 °C (0.15 mm). Analysis by GC (column A, 100 °C, 40 mL/min, t_R = 3.6 and 4.4 min) indicated the product was a 95:5 mixture of compounds, presumably the endo and exo isomers, respectively. The spectral properties of the product are as follows: IR (film) 2990, 2960, 2920, 2880, 1460, 1430, 1380, 1260, 1240, 1180, 1090, 1015, 945, 915, 890, 875, 830 cm^{-1}; ^1H NMR ($CDCl_3$) δ 0.96 (br td, 1 H, J = 8, 1.5 Hz, bridgehead H), 1.16 (s, 3 H, CH_3), 1.31 (s, 3 H, CH_3), 1.70 (dd, 1 H, J = 16, 1.5 Hz, 1 H of CH_2), 2.15 (br s, 2 H, CH_2), 2.38 (dd, 1 H, J = 16, 8 Hz, 1 H of CH_2), 2.94 (br s, 1 H, epoxide H), 3.05 (d, 1 H, J = 8 Hz, CHBr).

***endo*- and *exo*-7-Bromo-1,3-dimethylbicyclo[4.1.0]hept-3-ene *anti*- and *syn*-Oxides (30a–d)**: yield, 9.3 g (83%); bp 49–54

°C (0.15 mm). Analysis by GC (column A, 90 °C, 40 mL/min, t_R = 5.6, 6.3, 7.0, and 7.9 min) indicated the product was a 5:70:15:10 mixture of isomers, the major isomer presumably being the *endo*-bromocyclopropyl *anti*-oxide **30a**. The spectral properties of the product are as follows: IR (film) 2950, 1450, 1430, 1380, 1270, 1240, 1130, 950, 900, 835 cm^{-1}; ^1H NMR ($CDCl_3$) δ 0.8–1.0 (m, 1 H, bridgehead H), 1.17 (s, 2.4 H, CH_3 of anti isomers), 1.23 (s, 0.6 H, CH_3 of syn isomers), 1.30 (s, 2.4 H, CH_3 of anti isomers), 1.40 (s, 0.6 H, CH_3 of syn isomers), 1.7–2.0 (m, 2 H, CH_2), 2.3–2.6 (m, 2 H, CH_2), 2.87 (br s, 1 H, epoxide H), 3.00 (d, 1 H, J = 8 Hz, CHBr).

***endo*-9-Bromobicyclo[6.1.0]non-4-ene (17).** Reaction at 36 °C for 1 h without a solvent gave 2.91 g (84% crude yield) of a colorless liquid, bp 65 °C (0.5 mm). Purification by column chromatography (300 g of silica gel, elution with hexane) gave 1.80 g (52%) of monobromocyclopropane **17** as a colorless liquid. The IR and NMR spectral data of the product correspond to those reported by Osborn and co-workers.[30]

***endo*-3-Bromo-*endo*-tricyclo[3.2.2.0^{2,4}]non-6-ene (18).** Reaction at 20 °C for 2 h without a solvent gave 0.24 g (70%) of monobromocyclopropane **18** as a slightly yellow liquid after column chromatography (80 g of silica gel, elution with hexane): IR (film) 3060, 2950, 2850, 1650, 1460, 1375, 1310, 1280, 1260, 1175, 1070, 1045, 1010, 920, 845, 705 cm^{-1}; ^1H NMR (CCl_4) δ 1.0–1.7 (m, 6 H, 2 CH_2 and 2 cyclopropyl H), 2.29 (t, 1 H, J = 2 Hz, CHBr), 2.88 (br s, 2 H, two bridgehead H), 5.83 (dd, 2 H, J = 5, 3 Hz, 2 vinyl H).

***cis*- and *trans*-1-Bromo-2-(3-butenyl)cyclopropane Oxide (31a–d).** Reaction at room temperature for 1.5 h gave 20.6 g (83%) of monobromocyclopropyl epoxide **31** as a colorless liquid, bp 53–54 °C (0.3 mm). Analysis by GC (column A, 90 °C, 40 mL/min, t_R = 3.1 and 3.8 min) indicated the product was a 40:60 mixture of trans and cis isomers, respectively. The spectral properties of the product are as follows: IR (film) 3000, 2940, 2890, 2820, 1480, 1440, 1405, 1260, 1120, 1040, 915, 840 cm^{-1}; ^1H NMR ($CDCl_3$) δ 0.60 (apparent t, 1 H, J = 5 Hz, cyclopropane H), 0.7–1.6 (m, 2 H, 2 cyclopropane H), 1.72 (br s, 4 H, 2 CH_2), 2.50 (m, 1 H, epoxide H), 2.75 (apparent t, 1 H, J = 5 Hz, epoxide H), 2.8–3.2 (m, 2 H, CHBr and 1 epoxide H). Anal. Calcd for $C_7H_{11}BrO$: C, 44.00; H, 5.80. Found: C, 44.29; H, 5.68.

***endo*-Tricyclo[3.2.0.0^{2,7}]heptan-4-ol (1). General Procedure for Cyclization with *n*-Butyllithium.** A solution of 1.89 g (10.0 mmol) of monobromocyclopropyl epoxide **27** in 200 mL of THF was stirred and cooled at 0 °C as a 48-mL portion (120 mmol) of 2.5 M *n*-butyllithium in hexane was added slowly under a nitrogen atmosphere. After 4 h at 0 °C, the solution was hydrolyzed by slow addition of water. The organic product was extracted with three portions of ether, the solution was dried ($MgSO_4$), and the solvent was evaporated under reduced pressure to give 3.4 g of a deep yellow liquid. Column chromatography (300 g of silica gel, elution with 10% ethyl acetate–hexane) followed by distillation in a Kugelrohr oven at 100 °C (0.2 mm) gave 0.76 g (69%) of the known[2] tricyclic alcohol **1** as a colorless liquid: IR (film) 3300, 3000, 2900, 2820, 1330, 1280, 1075, 1005, 785, 770 cm^{-1}; ^1H NMR (CCl_4) δ 1.13 (apparent q, 1 H, J = 5 Hz, cyclopropane H), 1.4–1.8 (m, 3 H), 1.9–2.4 (m, 4 H, 2 CH_2), 2.25 (s, 1 H, OH), 4.25 (dt, 1 H, J = 10, 3 Hz, CHOH). Anal. Calcd for $C_7H_{10}O$: C, 76.33; H, 9.15. Found: C, 75.95; H, 9.15.

The following cyclic alcohols were prepared by the preceding procedure for the preparation of **1** with the deviations noted.

***endo*-2,7-Dimethyltricyclo[3.2.0.0^{2,7}]heptan-4-ol (34)**: yield, 1.1 g (84%); light yellow liquid. An analytical sample was obtained by preparative GC (column C, 135 °C, 80 mL/min); IR (film) 3300, 2900, 2820, 1450, 1335, 1080, 1045, 1000, 970, 900, 875 cm^{-1}; ^1H NMR (220 MHz, $CDCl_3$) δ 1.03 (s, 3 H, CH_3), 1.17 (s, 3 H, CH_3), 1.6–2.2 (m, 6 H), 2.52 (br s, 1 H, OH), 4.34 (dt, 1 H, J = 8.5, 4 Hz, CHOH). Anal. Calcd for $C_9H_{14}O$: C, 78.21; H, 10.21. Found: C, 78.09; H, 10.05.

***endo*-4,7-Dimethyltricyclo[3.2.0.0^{2,7}]heptan-4-ol (35).** Reaction with 2.2 equiv of *n*-butyllithium for 2 h gave 2.33 g (59%) of tricyclic alcohol **35** as a light yellow liquid: IR (film) 3300, 3000, 2900, 2820, 1440, 1360, 1290, 1260, 1220, 1180, 1130, 1050, 980, 950, 870, 810 cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.0 (m, 1 H), 1.15 (s, 3 H, CH_3), 1.18 (s, 3 H, CH_3), 1.6–2.1 (m, 6 H), 1.70 (s, 1 H, OH). Anal. Calcd for $C_9H_{14}O$: C, 78.21; H, 10.21. Found: C, 78.21; H, 10.16.

A small amount (~400 mg) of a yellow liquid slightly less polar than **35** was also isolated by column chromatography (400 g of silica gel, elution with 40% ethyl acetate–hexane). Analysis by GC (column A, 70 °C, 40 mL/min, t_R = 2.3, 2.8, 4.0, and 4.7 min) indicated the liquid was a 40:20:15:25 mixture of compounds. The ^1H NMR of the mixture is consistent with the presence of the isomeric secondary alcohol analogue of **37**.

***endo*-2,4-Dimethyltricyclo[3.2.0.0^{2,7}]heptan-4-ol (36) and *endo*-5,7-Dimethyltricyclo[3.2.0.0^{2,7}]heptan-4-ol (37).** Reaction with 2.0 equiv of *n*-butyllithium for 2.5 h gave 1.64 g (46%)[31] of tertiary alcohol **36** as an oily, low-melting solid and 0.375 g (10%)[31] of secondary alcohol **37** as a colorless oil. For **36**: IR (film) 3250, 2980, 2880, 1450, 1360, 1330, 1240, 1140, 1115, 1085, 1060, 1035, 995, 950, 920, 900, 850, 835 cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.02 (s, 3 H, CH_3), 1.24 (s, 3 H, CH_3), 1.1–1.4 (m, 2 H, 2 cyclopropane H), 1.5–2.3 (m, 5 H), 1.65 (s, 1 H, OH). Anal. Calcd for $C_9H_{14}O$: C, 78.21; H, 10.21. Found: C, 78.03; H, 10.40. For **37**: IR (film) 3300, 2900, 2820, 1455, 1375, 1260, 1080, 1055, 1030, 880, 860, 805 cm^{-1}; ^1H NMR ($CDCl_3$) δ 0.93 (apparent t, 1 H, J = 5 Hz, cyclopropane H), 1.08 (s, 3 H, CH_3), 1.17 (s, 3 H, CH_3), 1.1–1.8 (m, 4 H), 1.84 (s, 1 H, OH), 2.1–2.5 (9 line m, 1 H), 3.80 (apparent t, 1 H, J = 8 Hz, CHOH). Anal. Calcd for $C_9H_{14}O$: C, 78.21; H, 10.21. Found: C, 78.04; H, 10.10.

***endo*-Tricyclo[4.3.0.0^{5,7}]nonan-2-ol (38).** Reaction with 7.8 equiv of *n*-butyllithium at room temperature for 20 min gave 0.76 g (50%) of alcohol **38** as a colorless oily solid. An analytical sample was obtained by preparative GC (column D, 140 °C): IR (film) 3300, 3000, 2900, 2820, 1470, 1440, 1350, 1290, 1200, 1070, 1050, 1000, 970, 945, 890, 875, 790, 755 cm^{-1}; ^1H NMR (CCl_4) δ 0.6–0.8 (m, 1 H, cyclopropyl H), 1.0–2.2 (m, 10 H), 2.4 (m, 1 H, bridgehead H), 3.24 (s, 1 H, OH), 3.58 (dt, 1 H, J = 11, 4 Hz, CHOH). Anal. Calcd for $C_9H_{14}O$: C, 78.21; H, 10.21. Found: C, 78.06; H, 10.07.

***endo*-Tetracyclo[4.3.0.0^{3,8}.0^{7,9}]nonan-2-ol (39).** Reaction in hexane at room temperature for 3 days gave 1.06 g (84%) of alcohol **39** as a white solid: mp 196–198 °C (sealed tube); IR (Nujol) 3350, 1280, 1240, 1180, 1080, 1060, 1050, 1020, 955, 810, 785, 760, 720 cm^{-1}; ^1H NMR (220 MHz, CCl_4) δ 1.9–2.1 (m, 7 H), 2.0–2.5 (br m, 3 H, three bridgehead H), 2.81 (s, 1 H, OH), 3.94 (dd, 1 H, J = 6, 2 Hz, CHOH). Anal. Calcd for $C_9H_{12}O$: C, 79.37; H, 8.88. Found: C, 79.68; H, 9.07.

***endo*- and *exo*-Bicyclo[4.1.0]heptan-3-ol (40a,b) and *endo*- and *exo*-Bicyclo[3.1.0]hexane-2-methanol (41a,b).** Reaction of a 60:40 mixture of *cis*- and *trans*-monobromocyclopropyl epoxides **31a–d** with 8 equiv of *n*-butyllithium for 3 h gave 1.5 g (41%)[32] of a yellow liquid. Analysis by GC (column B, 80 °C, 40 mL/min, t_R = 5.6 and 6.3 min) indicated the product was a 40:60 mixture of primary alcohols **41a,b** and secondary alcohols **40a,b**, respectively. Analytical samples of each were obtained by preparative GC (column C, 140 °C, 85 mL/min, t_R = 12.9 and 14.9 min). The identity of the secondary alcohols as **40a,b** was established by comparison of their NMR and IR spectra and GC retention times with those of authentic samples prepared as described below. For **41a,b**: IR (film) 3300, 2980, 2900, 2840, 1450, 1060, 1040, 1020, 980, 845, 815 cm^{-1}; ^1H NMR ($CDCl_3$) δ 0.0–0.5 (m, 2 H, cyclopropane CH_2), 0.6–1.0 (m, 2 H, 2 bridgehead H), 1.1–1.9 (m, 4 H, 2 CH_2), 1.70 (s, 1 H, OH), 2.0–2.5 (m, 1 H, $CHCH_2OH$), 3.42 (dd, 0.7 H, J = 7, 2 Hz, CH_2OH of exo alcohol **41a**), 3.55 (d, 1.3 H, J = 7 Hz, CH_2OH of endo alcohol **41b**).

***exo*-Bicyclo[4.1.0]heptan-3-ol (40a)** was prepared according to the general procedure of Brown and co-workers[24a] from bicyclo[4.1.0]hept-3-ene *anti*-oxide (**45**), which was prepared by tin hydride reduction of **27** according to the procedure of Paquette et al.[13]

A solution of 2.0 g (18 mmol) of epoxide **45** in 25 mL of anhydrous ethylenediamine was stirred and cooled at 0 °C as 0.38 g (54 mmol) of lithium wire was added in small pieces over a period

(30) Osborn, C. L.; Shields, T. C.; Shoulders, B. A.; Cardenas, C. G.; Gardner, P. D. *Chem. Ind. (London)* **1965**, 766–9.

(31) The yields reported are based on the isomeric mixture of bromocyclopropyl epoxides **30a–d**. The yields are 65% and 15%, respectively, when based on *endo*-bromo *anti*-oxide **30a**, which comprises 70% of the isomeric mixture.

(32) The yield is based on the mixture of *cis*- and *trans*-bromocyclopropanes **31a–d**. The yield is 68% when based on *cis*-bromides **31a,b**, which comprise 60% of the isomeric mixture.

of 20 min under a nitrogen atmosphere. After 12 h at 0 °C, water was added, and the organic product was extracted with three portions of tetrahydrofuran and three portions of ether. The solution was dried ($MgSO_4$) and evaporated under reduced pressure to give 1.3 g (67% crude yield) of exo alcohol **40a** as a yellow liquid. An analytical sample was obtained by preparative GC (column C, 140 °C, 85 mL/min, t_R = 14.5 min). The IR and NMR spectral data correspond to those reported in the literature.[24c,33]

***endo*-Bicyclo[4.1.0]heptan-3-ol (40b)** was prepared by Simmons–Smith reaction of 3-cyclohexenol according to the procedure of Hanack and Krause.[24c] The product was removed from unreacted starting material by preparative GC (column C, 140 °C, 85 mL/min, t_R = 15.5 min). The IR and NMR spectral data correspond to those reported in the literature.[24c,33]

(33) Aumelas, A.; Casadevall, E.; Casadevall, A. *Tetrahedron* **1978**, *34*, 2481–90.

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Registry No. **1**, 39095-74-4; **2**, 82149-71-1; **3**, 628-41-1; **4**, 17351-28-9; **5**, 4074-22-0; **6**, 4190-06-1; **7**, 500-23-2; **8**, 111-78-4; **9**, 592-42-7; **10**, 6802-78-4; **11**, 38749-43-8; **12**, 66036-93-9; **13**, 66036-95-1; **14**, 24449-05-6; **15**, 82149-72-2; **16**, 32264-69-0; **17**, 2570-09-4; **18**, 82149-73-3; **19**, 71623-13-7; **20**, 71623-14-8; **21**, 82189-11-5; **22a**, 82149-74-4; **22b**, 82189-12-6; **23a**, 82149-75-5; **23b**, 82189-13-7; **24**, 64836-85-7; **25a**, 82149-76-6; **25b**, 82149-77-7; **26**, 82149-78-8; **27**, 82149-79-9; **28a**, 82149-80-2; **28b**, 82189-14-8; **29**, 82149-81-3; **30a**, 82149-82-4; **30b**, 82189-15-9; **30c**, 82189-16-0; **30d**, 82189-17-1; **31a**, 82149-83-5; **31b**, 82189-18-2; **31c**, 82189-19-3; **31d**, 82189-20-6; **34**, 82149-84-6; **35**, 82149-85-7; **36**, 82149-86-8; **37**, 82149-87-9; **38**, 82149-88-0; **39**, 64836-86-8; **40a**, 70064-28-7; **40b**, 40213-64-7; **41a**, 82149-89-1; **41b**, 78002-56-9; **42**, 51372-02-2; **43**, 82149-90-4; **44**, 33162-94-6; benzene, 71-43-2.

Synthesis of Adamantane Derivatives. 59.[1] Reactions of Some Electrophilic Adamantane Derivatives with Unsaturated Organosilanes

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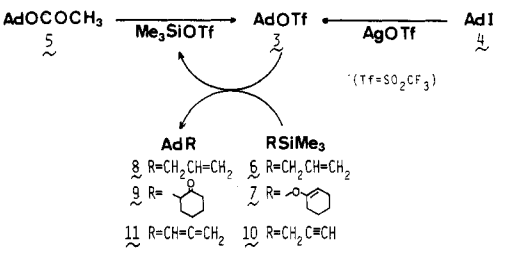
1-Adamantyl acetate (**5**) and 1-adamantyl silyl ether (**12**) react with unsaturated organosilanes exactly as the chloride **1** does; the reactions of **5** catalyzed by trimethylsilyl triflate and of **12** catalyzed by $TiCl_4$ with **6** and **7** give the corresponding adamantane-substituted products. Under $AlCl_3$-catalyzed conditions, the reactions of 1-adamantylcarbinyl chloride (**17**) with **6** and **7** give the products which have a homoadamantane skeleton. Interestingly, the reactions of 1-adamantanecarbonyl chloride (**22**) with α,β- and β,γ-unsaturated silanes proceed smoothly at −78 °C ($TiCl_4$) or at room temperature ($ZnCl_2$) while the competitive decarbonylation scarcely takes place. Furthermore, the reactions of **22** with silyl enol ethers are efficiently catalyzed with normal Lewis acids such as $SnCl_4$ to give C-adamantanecarbonylated products. Some adamantane-substituted unsaturated silanes are acetylated under the conditions employed for **22** to give structurally related adamantane derivatives. The aldehyde (**53**) and ketone (**54**) show different reactivity to the unsaturated organosilanes; the former reacts with **6**, **7**, and **25** as usual, but the latter does not.

The extensive growth of organosilicon chemistry has created a growing awareness of its considerable synthetic utility.[2] In the previous papers,[3] we reported the applicability of unsaturated organosilanes to the synthesis of adamantane derivatives: 1-Adamantyl (=Ad) chloride (**1**) was shown to be reactive with a variety of reagents categorized as X=Y—Z—$SiMe_3$, X≡Y—$SiMe_3$, and X=Y=Z—$SiMe_3$ (X, Y, and Z = C, N, O, and S) in the presence of Lewis acid, wherein the chemical behavior of an adamantyl cation was sometimes different from that of other electrophiles. In the present study we have chosen to examine the reactivity of the electrophiles obtained from adamantane derivatives other than the chloride **1**, i.e., acetate **5** and silyl ether **12** derived from the alcohol **2**, homologous chloride **17**, and carbonyl compounds **22**, **53**, and **54** which are electrophilic at the position adjacent to the bridgehead. Of particular interest is Lewis acid-catalyzed substitution reaction in the case of acid chloride **22** since few successful findings have appeared so far as a result of the intrinsic instability of the carbonyl cation, which tends to undergo decarbonylation. In addition, we have attempted the reactions of adamantane-substituted unsaturated silanes which give the products structurally related to those obtained from **22**.

Scheme I



Results

Reactions of AdOR (R = $COCH_3$, $SiMe_3$). Although **1** is a straightforward precursor for the bridgehead cation,

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