Acknowledgment. We gratefully acknowledge financial support from the University of South Carolina Venture Fund and Institutional Biomedical Research Support Grant NIH (08-S7RR07160K14). Support of high field NMR spectrometer purchases at the University of South Carolina by the NSF (CHE 84-11172) and the NIH (1-S10-RR02425) is acknowledged. We thank Dr. Ron Garber for his support and advice. We would especially like to thank Dr. Dave Deaton for the suggestion that we construct and evaluate **5**.

Supplementary Material Available: Full spectroscopic data for compounds **3** and **5** (17 pages). Ordering information is given on any current masthead page.

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Novel Silicon-Directed Alkylative Cyclization

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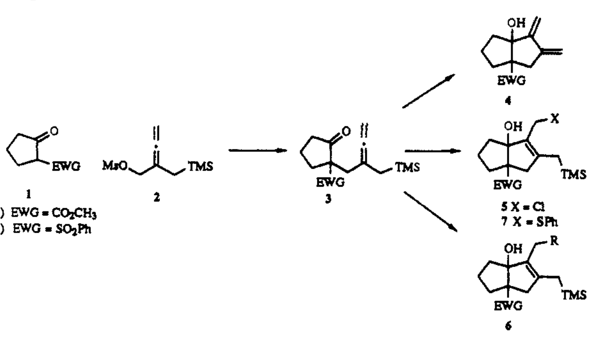
In conversion of simple building blocks to complex molecular arrays, enhanced efficiency results from synthetic methods that form more than one carbon–carbon bond in a single step (either concertedly or nonconcertedly). Cycloadditions represent examples of such reactions in which ring formation occurs as a result of more than one bond being formed between the two reacting partners. An alternative multibond ring-forming strategy involves a sequence of an intra- followed by an intermolecular bond formation as shown in q 1.[1] We record an example of such a process in which a silicon substituent plays a key role in promoting alkyl transfer without desilylation.

(1)

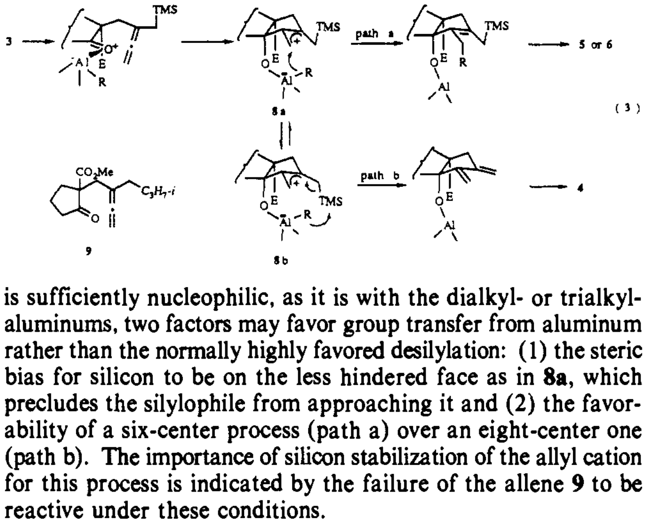
The allenyl silane **3**[2] (eq 2) readily forms by alkylation of the sodium salt of the appropriate precursor, the β-keto ester **1a** or β-keto sulfone **1b**, with the bifunctional conjunctive reagent **2** in THF at room temperature (**1a**, 82%) or DMF in the presence of 1 equiv of sodium iodide at 60 °C (**1b**, 79%). Lewis acid induced cyclization of **3** showed a remarkable dependence on the choice of acid. Exposing **3a** to 1.1 equiv of ethylaluminum dichloride in methylene chloride at −78 to 0 °C provides the desilylative cyclization product **4a** in 82% yield. TBAF in refluxing THF provides the same product in 75% yield, but the reaction is less clean. The sulfone **3b** cyclizes under these latter conditions to give a 78% yield of **4b**. The high reactivity of dienes such as **4** in Diels–Alder reactions makes such a simple annulation protocol for their direct formation valuable for polycyclic construction.



(2)

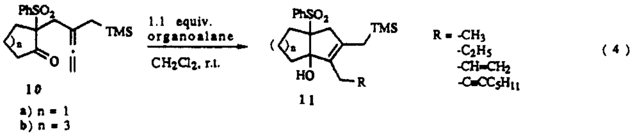
Switching to 1.1 equiv of dimethylaluminum chloride (4:1 methylene chloride–ether, room temperature) effected cyclization in 95% yield to form a 20:1 mixture of the very sensitive chloride **5b** and the diene **4b** in which the latter was the very minor constituent. Subjecting the crude cyclization reaction mixture to sodium benzenethiolate produced the stable sulfide **7b**, which was isolated in 79% overall yield from **3b**. Remarkably, chloride transfer superceded desilylation. An organoaluminum lacking any halide still promotes cyclization but with alkyl transfer rather than desilylation. Thus, exposing **3a** or **3b** to 1.1 equiv of trimethylaluminum (CH_2Cl_2, room temperature) produced the methylated cyclization product **6a** (R = CH_3, 81%) or **6b** (R = CH_3, 95%).

Equation 3 provides a rationale for the observation. It invokes the intermediacy of a silyl-stabilized allyl cation which may collapse by group transfer from aluminum to carbon (path a)[3] or by desilylation (path b).[4] If the complexed aluminum moiety is sufficiently nucleophilic, as it is with the dialkyl- or trialkylaluminums, two factors may favor group transfer from aluminum rather than the normally highly favored desilylation: (1) the steric bias for silicon to be on the less hindered face as in **8a**, which precludes the silylophile from approaching it and (2) the favorability of a six-center process (path a) over an eight-center one (path b). The importance of silicon stabilization of the allyl cation for this process is indicated by the failure of the allene **9** to be reactive under these conditions.



(3)

The reaction proves to be reasonably general both with respect to the alkyl group to be transferred and the annulation substrate. For example, the cycloheptanone produces the alkylative cyclization product **11b** (R = CH_3)[2] in 53% yield. Higher saturated alkylaluminums frequently engage in hydride transfer to carbocations, but in alkyl transfer in this system [eq. 4, $(C_2H_5)_3Al$, 80% (**11a**)[2]]. Depending upon the group to be transferred, some tuning of the organoalane is necessary. Whereas vinyl- and 1-heptynyldimethylalanes do not effectively participate, divinyl- and di-1-heptynylmethylalanes do [eq 4, $CH_3Al(CH{=}CH_2)_2$, 60% (**11a**); $CH_3Al(C{\equiv}CC_5H_{11}\text{-}n)_2$, 84–100% (**11a**), 52–78% (**11b**)],[2] with the group that can best stabilize anionic character exclusively transferring. On the other hand, organoboranes, such as triethylborane, do not effect alkylative cyclization.



(4)

We have previously shown that compounds like **11** (*n* > 3) can undergo Lewis acid catalyzed pinacol-like rearrangements in which the sulfone functions as a leaving group.[5] Telescoping the alkylative cyclization with cyclorearrangements produces the al-

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(1) For some examples involving transition-metal cascades, see: Negishi, E.; Tour, J. M. *Tetrahedron Lett.* **1986**, *27*, 4869; *J. Am. Chem. Soc.* **1985**, *107*, 8289. Fournet, G.; Balme, G.; Gore, J. *Tetrahedron Lett.* **1989**, *30*, 69. Semmelhack, M. F.; Kim, C. R.; Dobler, W.; Meker, M. *Tetrahedron Lett.* **1989**, *30*, 4925. For an example in radical cyclizations, see: Barton, D. H. R.; deSilva, E.; Zard, S. Z. *J. Chem. Soc., Chem. Commun.* **1988**, 285.

(2) All new compounds have been fully characterized spectrally.

(3) For overviews, see: Maruoka, K.; Yamamoto, H. *Tetrahedron* **1988**, *44*, 5001; *Angew. Chem., Int. Ed. Engl.* **1985**, *24*, 668. Negishi, E. *Organometallics in Organic Synthesis*; John Wiley & Sons: New York, 1980; pp 363–368.

(4) For recent reviews, see: Hosomi, A. *Acc. Chem. Res.* **1988**, *21*, 200. Schinzer, D. *Synthesis* **1988**, 263.

(5) Trost, B. M.; Adams, B. *J. Am. Chem. Soc.* **1983**, *105*, 4849.

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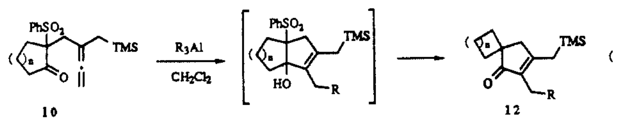
kylative cyclorearrangement of eq 5. Thus, using the eight-



10 12

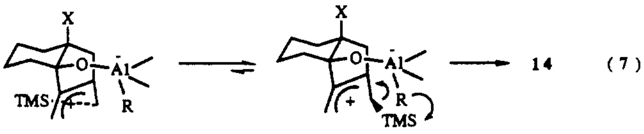
membered (**10**, $n = 4$) or twelve-membered (**10**, $n = 8$) substrates directly produces the spiro cyclopentenones **12** under the above conditions [$R = CH_3$, $n = 4$ (71%), $n = 8$ (67%); $R = C_2H_5$, $n = 8$ (71%)].[2]

The behavior of the cyclohexyl substrates **13a** and **13b** contrasts with the behavior observed for all of the other ring sizes (eq 6).

13 14

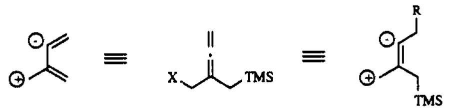
a) X = CO2Et
b) X = PhSO2

Only the products of desilylative cyclization **14a** (77%) and **14b** (82%) were observed with trimethylaluminum under conditions that produce only alkylative cyclization in the five-, seven-, eight-, and 12-membered rings. The conformational rigidity imposed by the cyclohexyl systems may account for this effect. In contrast to the other ring sizes, steric factors strongly destabilize conformer **15a**. The poising of the trimethylsilyl group for desilylation in **15b** allows the normal kinetic advantage of silyl transfer versus group transfer from aluminum to carbon to dominate, and only the diene **14** is obtained (eq 7).

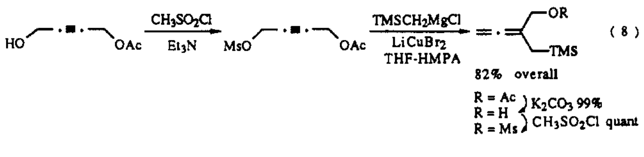


15a 15b

The bifunctional conjunctive reagent **2**, which is readily available from butyne-1,4-diol (eq 8), thus becomes a versatile synthon for cyclopentane annulation as summarized in structures **16** and **17**. Further, the results clearly indicate that, in such Lewis acid promoted additions of (allenylmethyl)silanes to carbonyl partners, the desilylation does not accompany carbon–carbon bond formation. The enhanced stability of the silyl-stabilized allyl cation allows its interception to provide an alkylative cyclization or desilylation simply by choice of Lewis acid. This is the first report of such a successful competition. This approach should allow creation of other alkylative cyclizations, as well as new bifunctional conjunctive reagents, to create different ring sizes and substitution patterns.



16 2 17



Acknowledgment. We thank the National Science Foundation for its generous support of our programs.

Supplementary Material Available: Summary of spectral data including ^1H and ^{13}C NMR and IR data for compounds **2–7** and **11–14** (8 pages). Ordering information is given on any current masthead page.

Structures of Organomagnesiate Ions Formed from Dialkylmagnesium Compounds and Alkali-Metal Alkoxides

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This study[1] was stimulated by observations that cryptands and crown ethers alter the reactivity of diorganomagnesium compounds. These additives are now known to cause disproportionation of R_2Mg to magnesiate ions such as R_3Mg^-, the reactive species, and coordinated RMg^+ cations, such as $RMg(cryptand)^+$.[2] We thought that appropriate salts could alter diorganomagnesium compounds in a similar fashion by forming magnesiate anions in which the anion of the salt is bonded to Mg, for example, $R_2Mg + KOMe \rightleftarrows$ "R_2MgOMe^-,K^+".

By dissolving organosodium or potassium compounds in solutions of $Mg(OR)_2$ ($OR = OCH_2CH_2OEt$), Screttas and Screttas have prepared solutions of composition $Na_2MgPh_2(OR)_2$,[3] $KMgPh(OR)_2$,[3] $Na_2MgBu_2(OR)_2$,[4] and $NaMgBu(OR)_2$.[4] In principle these might be the same as solutions prepared from Ph_2Mg or Bu_2Mg and NaOR or KOR, and in the case of $Na_2MgPh_2(OR)_2$, they concluded that both modes of preparation led to identical solutions.[5] They observed only single sets of ^1H and ^{13}C NMR absorptions for the solutions they studied and reached no structural conclusions. In earlier work, Ashby, Arnott, and Srivastava concluded that the major species in solutions formed from equimolar amounts of KH and R_2Mg had the molecular formula $K_2Mg_2R_4H_2$.[6]

We find that additions of alkali-metal alkoxides or some other salts to R_2Mg lead to behavior in some reactions resembling that of R_2Mg–cryptand preparations. This includes relatively ready addition to pyridine leading to 4-R-substituted as well as 2-R-substituted pyridines,[1,7] additions to ketones in which the accompanying reduction of the ketone is lessened or even eliminated,[8] and halogen–metal exchange with aryl bromides and iodides.[1,9]

Low solubility of many R_2Mg–salt combinations and chemical instability of some (RH is formed) limits systems suitable for structural studies. Systems having sufficient solubility (most studies have been in benzene), however, generally provide evidence for a species containing the elements of R_2Mg and the salt in equal amounts. When a salt itself is insoluble, solutions with a 1:1 composition commonly are attained, even when an excess of salt is used. At salt:R_2Mg ratios above about 0.5, a specific set of NMR absorptions often is seen that can be attributed to a 1:1 species; at a ratio of 1, only this set of absorptions remains. The ^1H NMR absorption of α-H's of R of a 1:1 species is at higher field than the equivalent absorption of R_2Mg.[10] At salt:R_2Mg ratios below 1, additional sets of NMR absorptions often are seen that are due to species having lower salt:R_2Mg ratios.

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(6) Ashby, E. C.; Arnott, R.; Srivastava, S. *Inorg. Chem.* **1975**, *14*, 2422.

(7) For related reactions of pyridine with solutions prepared from R_2Mg and RLi, see: Richey, H. G., Jr.; Farkas, J., Jr. *Organometallics*, in press.

(8) Richey, H. G., Jr.; DeStephano, J. P. *J. Org. Chem.*, in press.

(9) Stoudt, S. J., The Pennsylvania State University, unpublished results.

(10) For example, (CH_2Mg): (benzene-d_6) Hex_2Mg, δ 0.18; 1:1 Hex_2Mg–KOMe, δ −0.76.