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# Contrasting Reactivity in Lewis Acid-Promoted Reactions of Thio- and Silyl-Allenes with 1,4-Benzoquinones

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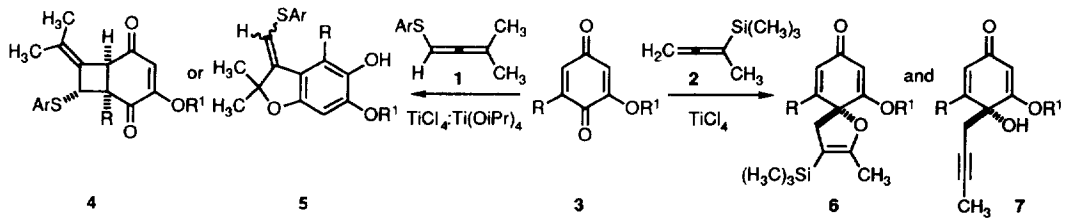
***Abstract:*** *In Ti(IV)-promoted reactions with 2-methoxy-1,4-benzoquinones 3, thioallenes 1 give 2+2 and/or 3+2 products via attack on a C=C moiety of the quinone, whereas silylallene 2 gives products derived from attack on a carbonyl group of the quinone.*

Lewis acid-promoted reactions of various alkenyl systems with 1,4-benzoquinones are remarkably versatile providing selective access to several different types of products. Diels-Alder products are formed in reactions with dienes,[1a] and bicyclo[4.2.0]octenediones, bicyclo[3.2.1]octenediones, and/or 2,3-dihydrobenzofuranols have been found in reactions with styrenyl systems.[1b-f] Some electron-rich alkenes yield products derived from 1,4-addition and allylsilanes and -stannanes give products of 1,2- or formal 1,4-addition, depending upon substituents present on the reactants.[2] As an unexplored area, we became interested in potential Lewis acid-promoted reactions of quinones with allenyl systems. Thioallenes have been shown to give products of formal 2+2 cycloaddition with various Michael acceptors[3] and silylallenes react with α,β-unsaturated ketones in the presence of Lewis acids to give 3-silyl-2-cyclopentenyl ketones in a useful 3+2 annulation procedure.[4,5] Seeking to develop similar processes utilizing quinones as the α,β-unsaturated carbonyl component in these reactions, we have examined Lewis acid-promoted reactions of thioallene **1** and silylallene **2** with various 2-alkoxy-1,4-benzoquinones. Our preliminary results reported herein indicate that the two allenes give very different kinds of products; thioallene **1** produces **4** and/or **5** via attack on a C=C moiety of the quinone, whereas silylallene **2** gives **6** and **7**, or products derived from them, via attack on a carbonyl group of the quinone.




Treatment of quinones **3a/b** with Ti(IV), as mixtures of $TiCl_4$:$Ti(OiPr)_4$, in $CH_2Cl_2$ at -78 °C followed by addition of allene **1a**[6] gave, after quenching with solid $NaHCO_3$/iPrOH and then $H_2O$, extraction ($CH_2Cl_2$) and chromatography (silica gel, acetone/hexanes), cyclobutanes **4a/b**[7a] (Scheme I and Table 1). Reaction of allene **1b** with quinone **3a** gave cyclobutane **4c**[7a] and benzofuran **5c**.[7b] Upon warming the reactions to -20 °C or room temperature, the major products were benzofurans **5**[7b] as inseparable mixtures of double bond isomers in which the *E*-isomer predominated (>2:1). Reaction of quinone **3c** with allene **1a** required warming

to room temperature and gave only the benzofuran product **5d**,[7a] exclusively as the opposite *Z*-isomer, presumably for steric reasons. Selective decoupling of the allylic methyl groups in **4a** identified the H-6 and H-8 NMR signals and, by default, the H-1 signal as well. The position of the C-3 methoxy group in **4a** was then determined by an HMBC experiment and the stereochemistry assigned by $^1$H-$^1$H NOE experiments.[8] The substitution pattern and stereochemistry in **4b/c** were assigned by spectral comparison with **4a** and confirmed by single crystal X-ray analysis of **4c**. In benzofurans **5a-c**, the appearance of H-4 and H-7 as non-coupled singlets supports the assignment of the C-6 methoxy group. The stereochemistry in benzofurans **5** was again established from $^1$H-$^1$H NOE experiments.[8]

**Scheme I**

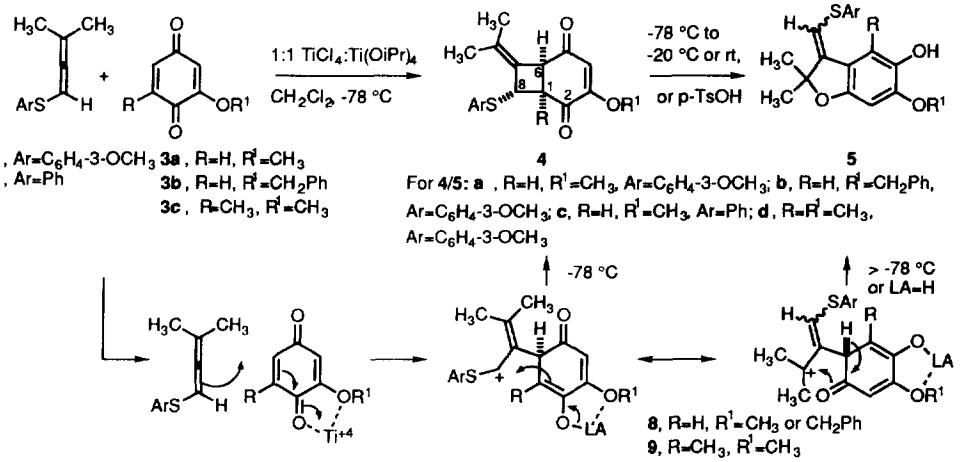



**Table 1. Ti(IV)-Promoted Reactions of Thioallenes 1a/b with Quinones 3.**

| Entry | Allene | Quinone | Lewis acid[a] | Temp (°C) | Product(s) (% yield)[b] |
|---|---|---|---|---|---|
| 1 | **1a** | **3a** | 2.8:1 $TiCl_4$:$Ti(OiPr)_4$ | -78 | **4a** (29) |
| 2 | **1a** | **3b** | 3:1 $TiCl_4$:$Ti(OiPr)_4$ | -78 | **4b** (53) |
| 3 | **1b** | **3a** | 2:1 $TiCl_4$:$Ti(OiPr)_4$ | -85 | **4c** (35) + **5c** (21) |
| 4 | **1a** | **3a** | 3:1 $TiCl_4$:$Ti(OiPr)_4$ | -78 -> -20 | **5a** (69) |
| 5 | **1a** | **3b** | 2.8:1 $TiCl_4$:$Ti(OiPr)_4$ | -78 -> -20 | **5b** (64) |
| 6 | **1b** | **3a** | 2.8:1 $TiCl_4$:$Ti(OiPr)_4$ | -78 -> -20 | **4c** (15) + **5c** (39) |
| 7 | **1a** | **3c** | 1:1 $TiCl_4$:$Ti(OiPr)_4$ | -78 -> rt | **5d** (37) |

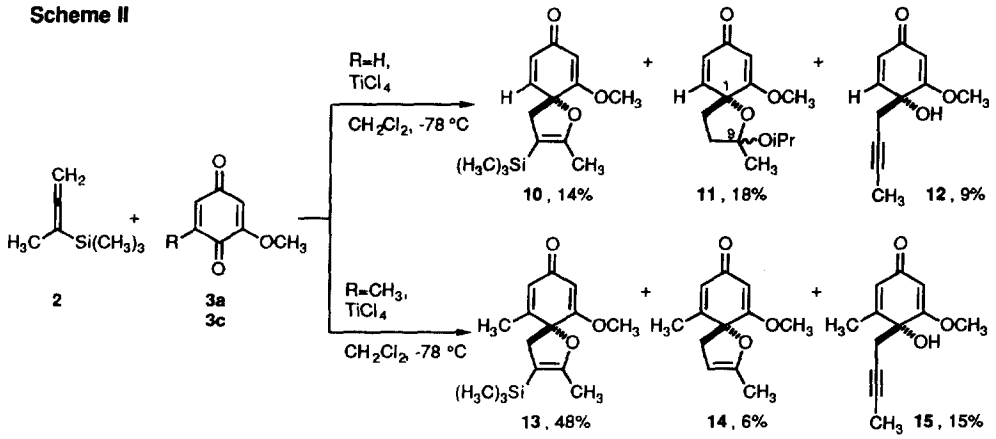
[a]One equiv Ti(IV) with respect to quinone. [b]Not optimized.

Mechanistically, these reactions probably proceed via regioselective nucleophilic attack of the thioallene on the Lewis acid-activated quinone to give carbocations **8/9** (LA=$Ti^{+3}$); at low temperature, **8** closes to cyclobutanes **4a-c**, whereas at higher temperature, benzofuran **5** is found through C-O bond formation and loss of $H^+$.[9] In related experiments, treatment of **4a/b** with p-TsOH/$CH_2Cl_2$ at room temperature effects their rearrangement to **5a/b** (~62/85%), again as a mixture of isomers, presumably through carbocation **8** (LA=H). Intermediate carbocation **9** gives only benzofuran **5d** via C-O bond formation and loss

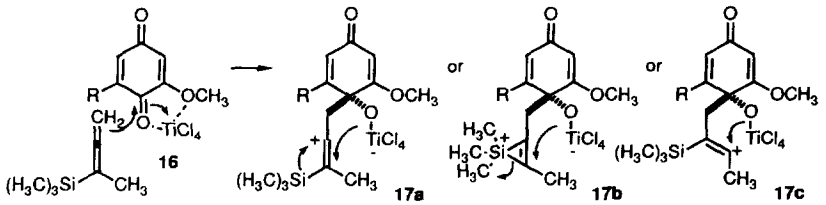
of $H^+$, most likely due to steric hindrance to C-C bond formation.

On the other hand, $TiCl_4$-promoted reactions of allenylsilane **2**[4f] with quinones **3a/c** gave the spirocyclic ethers **10/11** and **13/14**, respectively, as major products, accompanied by homopropargylic alcohols **12** and **15** (Scheme II);[7] similar products are found in Lewis acid-promoted reactions of silylallenes with aldehydes.[4e] Although ketal **11** was formed as a single diastereomer, the relative configuation at C-1 and C-9 has not been assigned. The positions of the substituents in spirocyclic ethers **10/13**, ketal **11** and homopropargylic alcohol **12** were assigned from HMBC NMR experiments.[10] The structure of alcohol **15** was assigned by spectral comparison to alcohol **12** and ether **13**, and that of desilylated dihydrofuran **14** was assigned by spectral comparison to **13**; in the latter comparison, the major differences were the absence of a TMS group in **14** along with the appearance of a signal at 4.63 ppm which was coupled to the C-7 $CH_2$ in the $^1H$ NMR (all other spectral data was as expected).

**Scheme II**




The formation of spirocyclic ethers **10** and **13** probably involves 1,2-alkylation of the Ti(IV)-quinone complex **16** by the allenylsilane to give the β-silylcarbocation **17** which can be represented as **17a, b** or **c**. A [1,2]-silyl group migration with C-O bond formation, i. e. from **17a/b**, or C-O bond formation in **17c**, then gives **10/13**. Alternatively, desilylation of **17a-c**, perhaps by chloride ion present in the reaction mixture, followed by aqueous workup accounts for the formation of homopropargylic alcohols **12/15**. Compound **14** may be formed from **13** by desilylation under the reaction conditions or by reaction with HCl generated during quenching the reaction. Similarly, ketal **11** may be formed from **10** by prototopic desilylation and acid-catalyzed addition of iPrOH on workup.




We continue to explore the generality, limitations and synthetic utility of these reactions.

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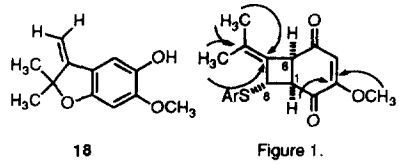
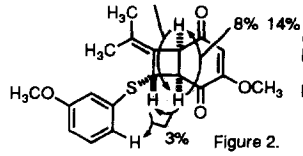
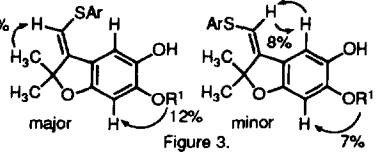
6. Allenes **1a/b** were prepared by reaction of 3-methoxythiophenol and thiophenol, respectively, with 3-chloro-3,3-dimethylpropyne in the presence of $K_2CO_3$ and KI in refluxing acetone.

7. a) These compounds exhibited expected spectral data (300 HMz $^1H$ NMR, 75 MHz $^{13}C$ NMR, IR and mass) and exact mass and/or elemental analyses. b) Identified by NMR and by desulfurization (nickel boride, EtOH/$H_2O$, gentle reflux) of the mixture to a 1:1 mixture of **18** and 6-methoxy-2,2,3-trimethyl-2,3-dihydrobenzofuran-5-ol (87%) followed by further reduction of this mixture ($H_2$, Pd/C, EtOH, rt) to afford only the latter compound (91%).



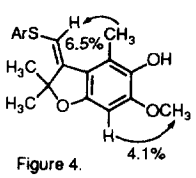



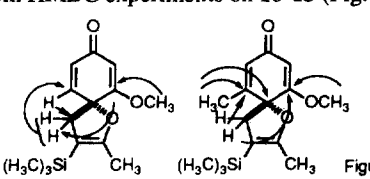




8. Selected data from an HMBC experiment on **4a** (Fig.1) and $^1H$-$^1H$ NOE experiments on **4a** (Fig. 2), **5c** (Fig. 3) and **5d** (Fig. 4, see below).

9. A preference for cyclobutane formation at low temperature in Ti(IV)-promoted reactions of styrenes with quinones, which are thought to proceed via intermediates similar to **8/9**, has been noted; see references 1b/f.

10. Selected data from HMBC experiments on **10-13** (Fig. 5).

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