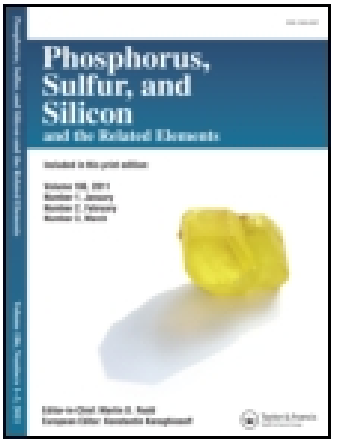


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# Some Recent Advances in Pummerer-type Reactions

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# Some Recent Advances in Pummerer-type Reactions

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A highly enantiomeric excess in an asymmetric Pummerer-type rearrangement of chiral, non-racemic sulfoxides using *O*-silylated ketene acetal and the first successful Pummerer-type rearrangement on aromatic rings, are described.

## INTRODUCTION

The Pummerer and Pummerer-type rearrangements of sulfoxides have received considerable attention both mechanistically and as a synthetically useful process for the preparation of α-substituted sulfides, including α-acetoxy, α-alkyl, α-aryl, α-halo, and α-siloxy-substituted species.[1] Although many useful applications have been reported for these reactions, there is no successful report on an asymmetric Pummerer rearrangement of optically active sulfoxides and a Pummerer-type rearrangement on aromatic rings. We found the first highly enantioselective Pummerer-type rearrangement of chiral, non-racemic sulfoxides using *O*-silylated ketene acetal and a novel aromatic Pummerer-type rearrangement of *p*-sulfinylphenol derivatives leading to *p*-quinones or protected dihydroquinone derivatives.

## ASYMMETRIC PUMMERER-TYPE REARRANGEMENT

The Pummerer rearrangement of sulfoxides was first reported by Pummerer in 1909,[2] and the reaction was later examined in detail by Horner.[3] Subsequently, a huge amount of splendid studies by Oae of the Pummerer rearrangement using $^{18}O$ tracer experiments showed intramolecular rearrangements to be involved, and now a general mechanism for the Pummerer rearrangement consisting of four sequential elemental reactions can be considered (Figure 1).[1]

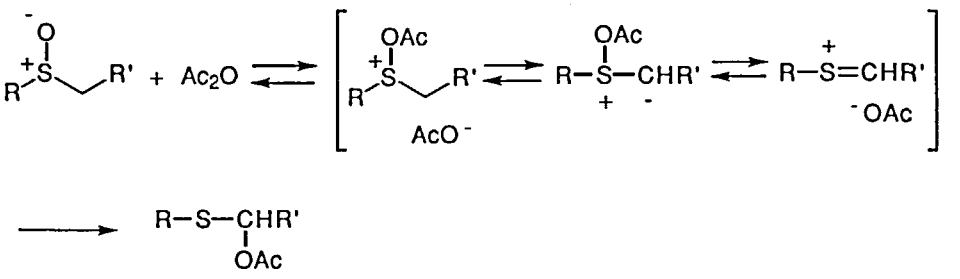


FIGURE 1 General mechanism for the Pummerer rearrangement.

The stereoselective Pummerer rearrangement of optically active sulfoxides is a self-immolative asymmetric transformation and is of considerable interest, because of its potential to provide a means of synthesizing chiral, non-racemic α-substituted sulfides. In fact, the stereogenicity transfer from the sulfur of chiral, non-racemic sulfoxides to the α-carbon has been reported.[4] In the late 1970s, the first asymmetric Pummerer rearrangement of chiral acyclic sulfoxides was independently reported by Oae[5] and Mikolajczyk.[6] The extent of the chiral transfer from chiral acyclic sulfoxides, however, was quite low and never exceeded 30% ee probably due to the formation of a sulfurane intermediate by reaction with the generated acetate anion. Racemization of the chiral sulfoxides also occurred under most of the reaction conditions used. Although the stereoselectivity was improved to 70% ee by the addition of 1,3-dicyclohexyl carbodiimide (DCC) to act as an effective scavenger of the acetate anion and acetic acid, the chemical yield decreased to 10%.[7] The Pummerer reaction of chiral benzyl tolylsulfoxide even in the presence of DCC gave only a racemic adduct[8] (Figure 2).

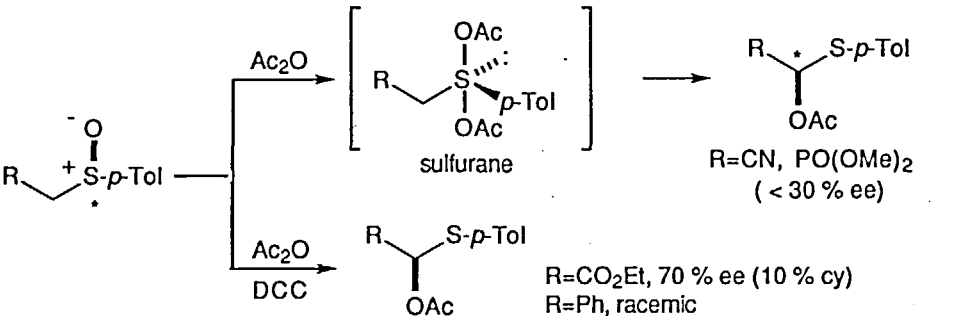


FIGURE 2 Pummerer rearrangement of optically active sulfoxides.

However, the use of an effective silylating reagent, *O*-methyl *O*-*tert*-butyldimethylsilyl ketene acetal (**1**)[9] was expected to act as an effective reagent in an asymmetric Pummerer-type rearrangement[10] because the reaction using **1** proceeds under quite mild conditions and in high yields without forming sulfuranes. Therefore, we examined the reaction of chiral, racemic *syn*- and *anti*-β-substituted sulfoxides (**2**) with **1** in the presence of a catalytic amount of zinc iodide in MeCN. All reactions proceeded under mild conditions with high chemical yields and a remarkably high degree of stereospecificity.[11] We were surprised to find that extremely high retention occurred in all β-siloxy, β-acylamino-, β-alkylamino, β-alkyl- and β-aryl substituted sulfoxides and, of course, in both the racemic and non-racemic sulfoxides (Figure 3).

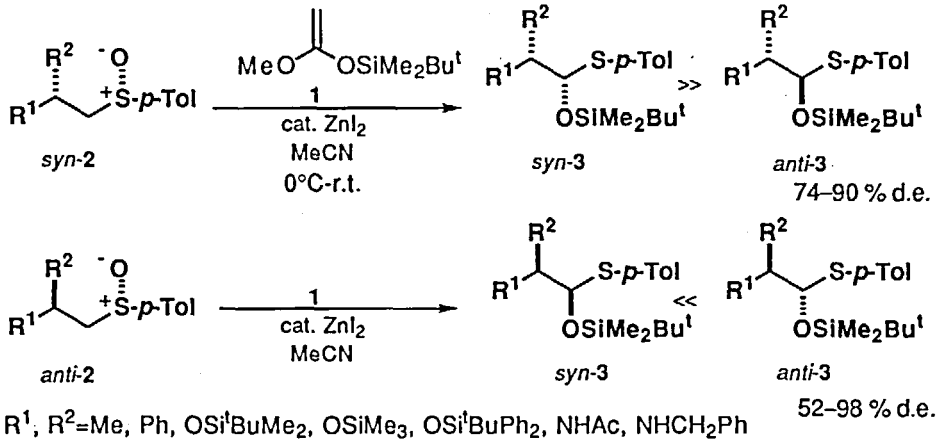



FIGURE 3 Asymmetric silicon-induced Pummerer-type reaction.

Contrary to these findings, in a normal Pummerer reaction of *syn*- and *anti*-**2** ($R^1$=Ph, $R^2$=$OSi^tBuMe_2$) with hot acetic anhydride.both gave the same 80:20 ratio of diastereomeric α-acetoxysulfides[12] (Figure 4).

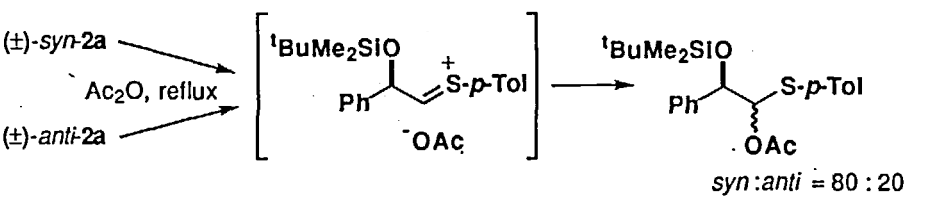
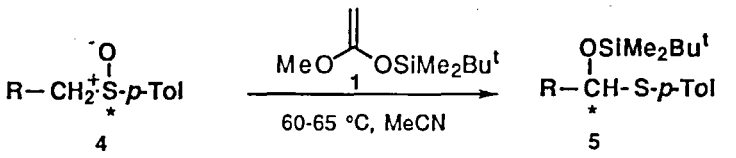



FIGURE 4 Normal Pummerer reaction of *syn*-and *anti*-β-substituted sulfoxides.

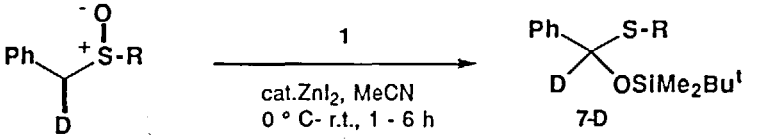
In order to ascertain the effect of the sulfoxide itself, we next examined the reaction of **1** with the known chiral, non-racemic sulfoxides (**4**) which has a stereogenic center on the sulfur atom. The sulfoxides (**4**) were treated with **1** in the absence of a catalyst in MeCN to give the corresponding chiral, non-racemic α-siloxy sulfides (**5**). In each case, the optical purity and chemical yields of the Pummerer adducts were greater than those from the original approach[13] (Table 1).

TABLE 1
Asymmetric silicon-induced Pummerer-type reactions.




| Sulfoxide | R | Condition | % E.e. (% Yield) | $[\alpha]_D^{10}$ (c, acetone) | Configuration |
|---|---|---|---|---|---|
| *S*-**4a** | $CO_2Et$ | 4h | 87 (75) | +35.8 (0.46) | *S* |
| *R*-**4a** | $CO_2Et$ | 4h | 86 (72) | -34.8 (0.67) | *R* |
| *S*-**4b** | $CONMe_2$ | 12h | 88 (65) | -28.9 (1.4) | *S* |
| *R*-**4b** | $CONMe_2$ | 12h | 88 (69) | +28.8 (1.23) | *R* |

While the general scheme of the Pummerer rearrangement is believed to be that shown in the four sequential elemental reaction steps, it is of interest to know which step causes the asymmetric induction. Wolfe and Kazmier studied the diastereotopic selectivity of the deprotonation step of the *syn*- and *anti*-α-deuteriobenzyl methylsulfoxides (**6**) under normal Pummerer conditions.[14] According to their findings, little selectivity was observed because of the competing epimerization at the sulfur via the sulfurane intermediate. We investigated the reaction of **6** with **1** and found that the deprotonation of the α-proton occurred with high diastereoselectivity.[15] These results suggested that **7** was produced by selective abstraction of the sulfinyl *pro-R* hydrogen in *R*-**6** (Figure 5).




(±)- *syn*-**6** R=Me, Bu^t

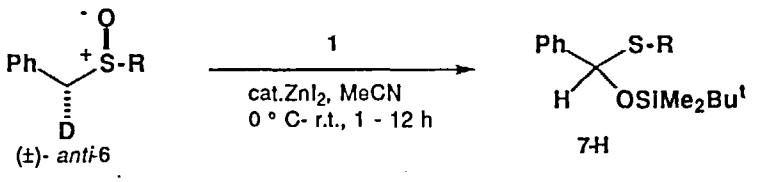



FIGURE 5 Silicon-induced Pummerer-type reaction of α-deuterio Sulfoxides.



The following mechanism is proposed to explain these results. Silylation of *R*-**6** with **1** affords the intermediate **A**, which may yield an anion intermediate **B** through abstraction of an *anti*-periplanar hydrogen from the opposite face of the sulfoxide oxygen by a generated ester enolate anion. The siloxy group may then be forced to migrate to the α-position via one of the following three mechanisms; i) intimate ion pair mechanism ii) radical dissociation-recombination mechanism[16] or iii) direct carbanion attack (Figure 6).

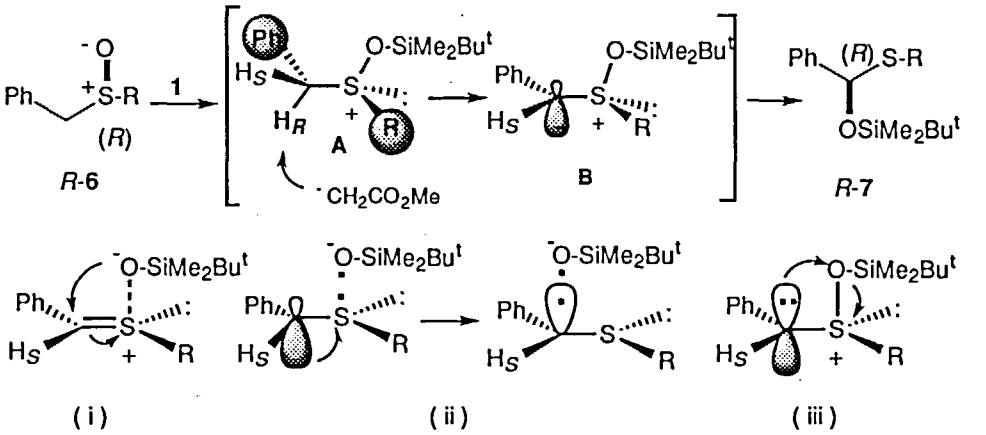



FIGURE 6 Plausible mechanism of silicon-induced Pummerer-type reaction.

It is easier to understand the reaction mechanism of the asymmetric Pummerer rearrangement of α-deuterio cyclic sulfoxides than that of acyclic sulfoxides. The reaction of rigid cyclic sulfoxides (**8**) with **1** proceeded *via* a *trans* E2-type elimination to give α-siloxysulfides with extremely high retention of the stereochemistry of the starting sulfoxides; *trans*-1-thiadecalin 1-*axial*-oxide (*ax*-**8**) gave *equatorial*-α-siloxysulfide (*eq*-**9**) and *trans*-1-thiadecalin 1-*equatorial*-oxide (*eq*-**8**) gave 1-*axial*-α-siloxysulfide (*ax*-**9**), respectively.[15] In contrast to our

findings with **1**, treatment of *ax*-**8** and *eq*-**8** with acetic anhydride in the absence or presence of DCC gave the *equatorial* α-acetoxysulfide in each case.[17] While the mechanism of the siloxy group migration may involve either i) an intimate ion pair mechanism or ii) a radical dissociation-recombination mechanism, that of the acetoxy group probably implies a sulfonium ion (Figure 7).

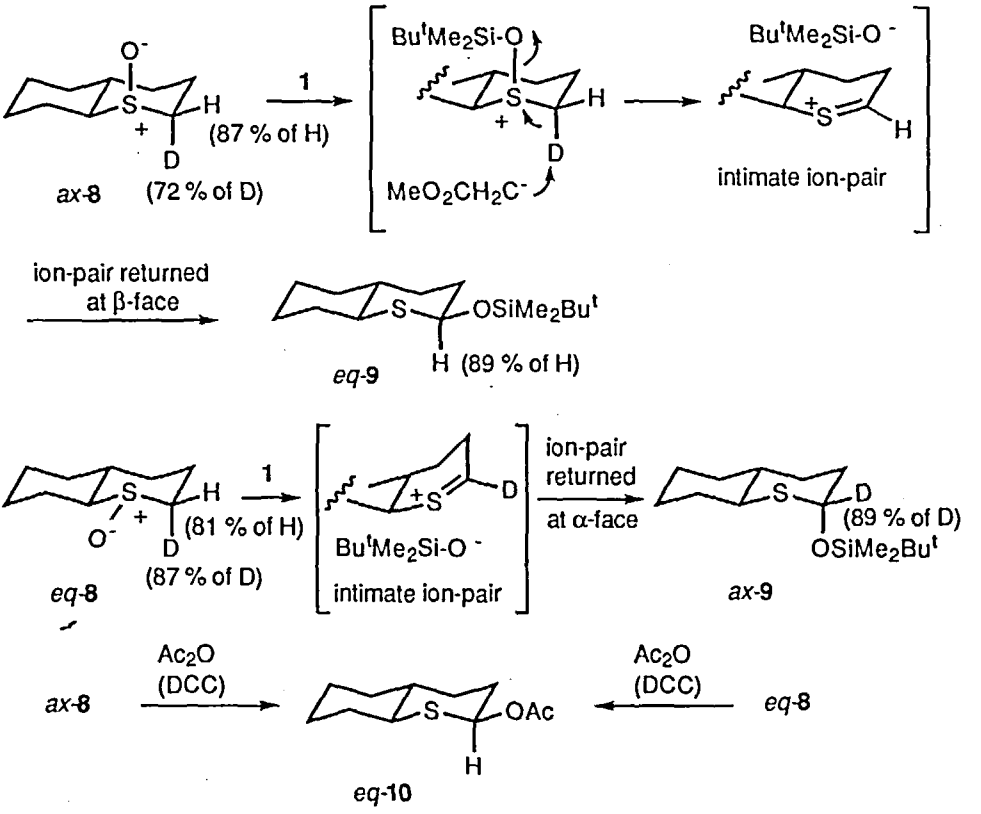



FIGURE 7 Asymmetric Pummerer-type rearrangement of α-deuterio sulfoxides.

We have described the first highly asymmetric silicon-induced Pummerer-type rearrangement in chiral, non-racemic sulfoxides using **1**, which gave chiral non-racemic α-siloxysulfides under mild conditions in high yield. However, the extent of the asymmetric transformation never exceeded 90% ee. To develop the optimal asymmetric transformation of sulfoxides, it is quite important to determine in which step(s) racemization occurs.

We determined that the deprotonation step of the α-methylene protons plays a significant role in the stereoselectivity; therefore, we selected compounds **11** which have two stereogenic centers, at the α-carbon and the sulfur atom. Surprisingly, high stereogenic transfer was observed in the reaction of **11** with **1**.[18] Thus treatment of *syn*-**11** with **1** in the presence of a catalytic amount of zinc iodide in THF gave enantiomerically pure α-siloxy sulfide (**12**) and the reaction of *anti*-**11** with **1** likewise gave pure **12**. Interestingly, the stereochemistry of the sulfoxide had no effect on the configuration of the product. The introduction of a stereogenic center α– to a sulfoxide dramatically improved the enantioselectivity from 88% ee to >99% ee. The results showed that the deprotonation step is the most important for high enantiomeric purity and an optimal asymmetric Pummerer reaction of chiral non-racemic acyclic sulfoxides was accomplished by controlling this step. The synthesis of enantiomerically pure quaternary substituted carbon compounds as well as complete asymmetric transfer in the Pummerer rearrangement is especially noteworthy (Figure 8).

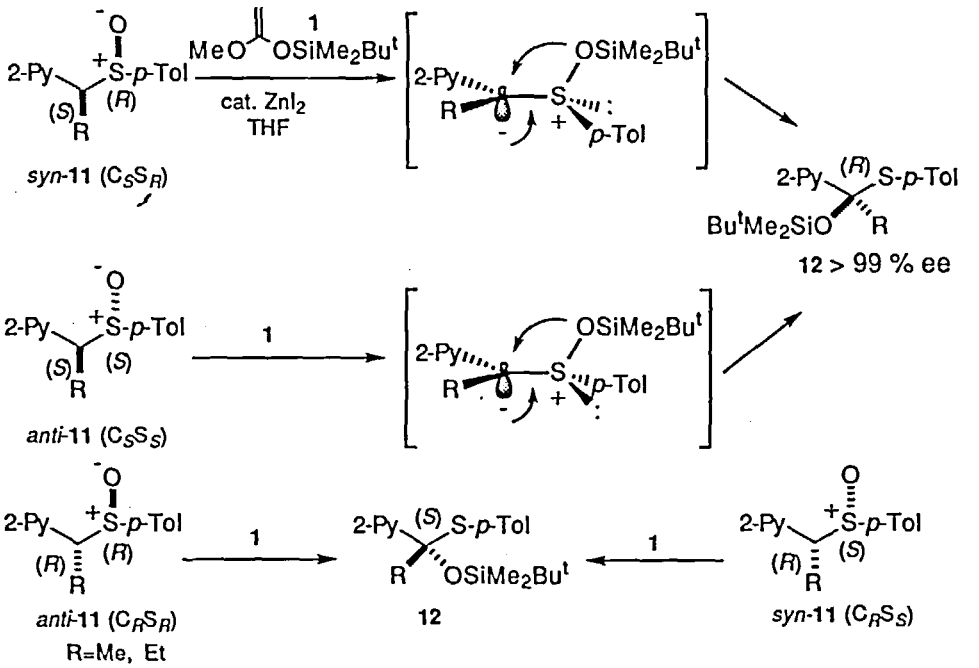



FIGURE 8 Enantioselective Pummerer-type rearrangement of α-substituted sulfoxides.

The main reason for the high asymmetric induction of the silicon-induced Pummerer-type reactions seems to be the absence of sulfurane formation. Therefore, we examined a novel asymmetric Pummerer reaction using a similar type of acyl-inducing reagent, ethoxy vinyl ester **13a** (R=Me),[9, 19] which is known to be a powerful acylating reagent for active hydrogen compounds such as alcohols, amines, and carboxylic acids and found that **13a** (R=Me) brought about a highly asymmetric Pummerer rearrangement of chiral sulfoxides to give α-acetoxy sulfides (**14**).[20] Treatment of sulfoxides with **13a** in refluxing 1,2-dichloroethane, benzene or toluene gave chiral **14** in very high ee. The observed optical and chemical yields were higher than those of the reported asymmetric Pummerer rearrangement using an acid anhydride. Although the asymmetric induction of the present asymmetric Pummerer rearrangement is slightly lower than that of the silicon-induced type, it is quite interesting that the asymmetric induction is increased by preventing the formation of the sulfurane intermediate (Figure 9).

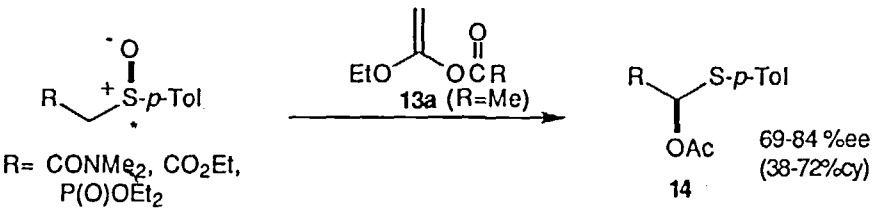



FIGURE 9 Pummerer-type reaction of chiral, non-racemic silfoxides with ethoxy vinyl ester.

## ASYMMETRIC INTRAMOLECULAR PUMMERER-TYPE CYCLIZATION

The intramolecular Pummerer cyclization is particularly useful in natural product chemistry because of its mild conditions. ω-Carbamoylsulfoxides undergo an intramolecular Pummerer-type cyclization with **1** in MeCN in the presence of a catalytic amount of zinc iodide to give sulfenyl-*N*-heterocycles including 4- to 7-membered α-sulfenyl lactams in good to excellent yields under nearly neutral conditions.[21] β-Amido sulfoxides react with **1** to give 4-phenylthioazetidin-2-ones (**15**)[22, 23] (Figure 10).

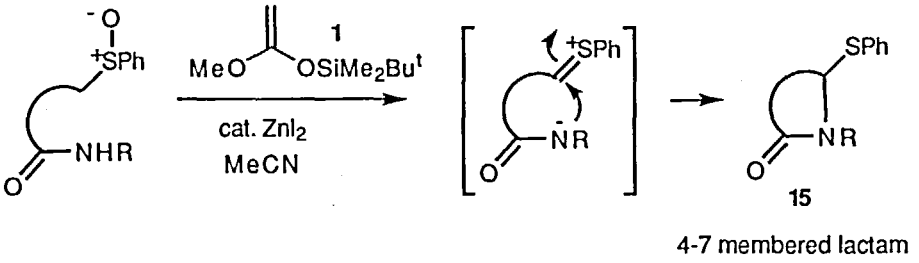



FIGURE 10 Intramolecular Pummerer-type cyclization of ω-amidosulfoxides.



This silicon-induced intramolecular Pummerer-type cyclization is also effective for the synthesis of carbapenem antibiotics such as (+)-PS-5 and (+)-thienamycin. The oxidation of **16** with *m*-chloroperbenzoic acid (mCPBA) gives the corresponding sulfoxides (**17**), which when treated with **1** selectively give the *trans* azetidin-2-one esters (**18**). The reaction of **17** with **1** presumably proceeds via an acyliminium intermediate **C**, shown in Figure 11; initial silyl transfer from **1** to the sulfoxide oxygen and subsequent elimination of the phenylsulfinyl group by the electron donating effect of the nitrogen atom would give an acyliminium intermediate **C**, which would then undergo nucleophilic attack by the generated ester enolate anion at the 4-position to give **18**. Similarly, **17** reacted with silylated heteronucleophiles (Y-SiMe3) to give the corresponding *trans* 4-heterofunctionally substituted azetidin-2-ones in high yields[24, 25].

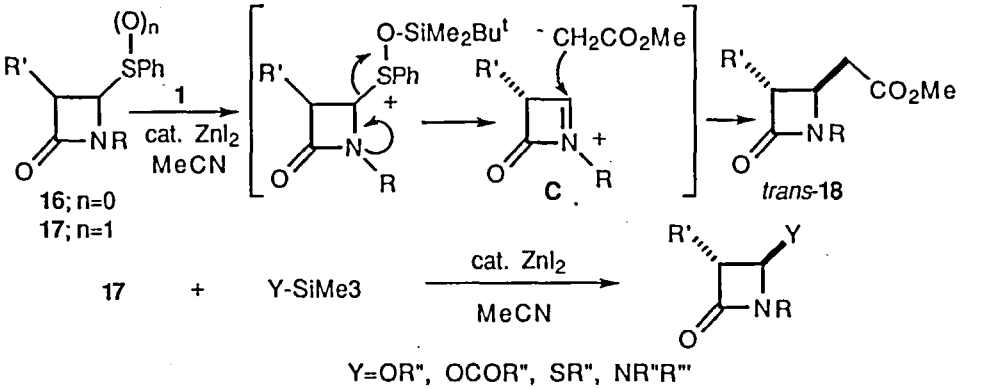


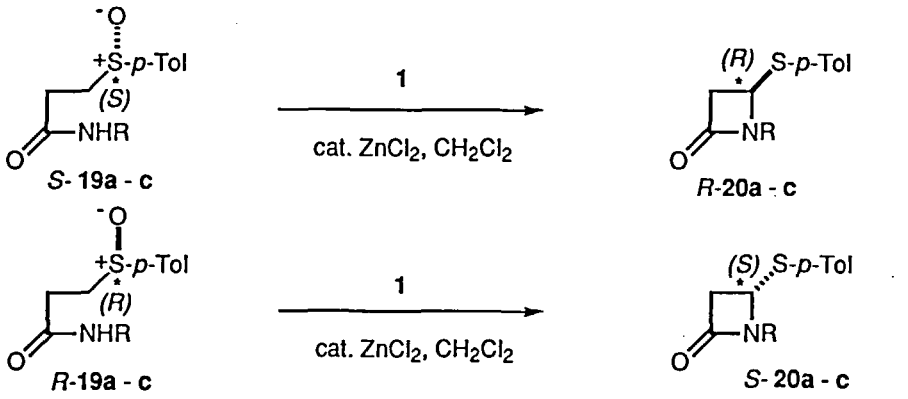

FIGURE 11 Substitution reaction of 4-sulfinylazetidin-2-ones.

The asymmetric version of an intramolecular Pummerer-type cyclization is quite useful for the synthesis of optically active heterocyclic compounds. Only a few examples of these types of reactions have been reported, and the ee yields were low. An example of an asymmetric intramolecular Pummerer cyclization was reported by Allenmark in 1974[26] and Wolfe in 1979[27] for the synthesis of chiral γ-lactones (< 30% ee). The stereoselectivity in this reaction was improved to 67 % ee by Kaneko in 1987[28] using trimethylsilyltrifluoromethanesulfonate (TMSOTf) / diisopropylethylamine.

We applied our silicon-induced intramolecular Pummerer-type cyclization to the asymmetric version of chiral, non-racemic β-amidosulfoxides (**19a-c**) and found that the reaction of *S*- and *R*-**19a-c** with **1** in the presence of a catalytic amount of zinc chloride in $CHCl_2$ gave the corresponding 4*R*- and 4*S*-β-lactams (**20**) in more than 80% ee[29] (Table 2). These results show that the stereo-induction is influenced by the absolute configuration of the sulfoxides. The present Pummerer-type cyclization shows the highest optical induction of all previously examined methods.

TABLE 2

Asymmetric Pummerer-type cyclization of chiral, non-racemic sulfoxides.




| Sulfoxide | R | % E.e. (% Yield) | Product | $[\alpha]_D$ (*c*, $CHCl_3$) |
|---|---|---|---|---|
| *S*-**19a** | *S*-CH(Me)Ph | 82 (96) | R | -98.8 (1.96) |
| *R*-**19a** | *S*-CH(Me)Ph | 85 (89) | S | +116 (0.954) |
| *S*-**19b** | $CH_2Ph$ | 80 (54) | R | -73.2 (1.01) |
| *R*-**19b** | $CH_2Ph$ | 82 (54) | S | +75.2 (0.934) |
| *S*-**19c** | $CHPh_2$ | 80 (84) | R | -37.0 (0.303) |
| *R*-**19c** | $CHPh_2$ | 83 (90) | S | +38.4 (0.522) |

The following mechanism is proposed to explain the results and a transition state is postulated for the reaction of *S*-**19** with **1**. Silylation of *S*-**19** with **1** affords the intermediate **D**. Thus **D** may yield à chiral pseudo isothiazolone derivative **E** through *axial* attack on the sulfur by the amino anion, generated by proton abstraction with the ester enolate anion, and elimination of the siloxy ligand. The hydrogen neighboring the sulfur atom is then removed by the siloxy anion and the amido ligand migrates from the α-face to give *R*-**20** (Figure 12).

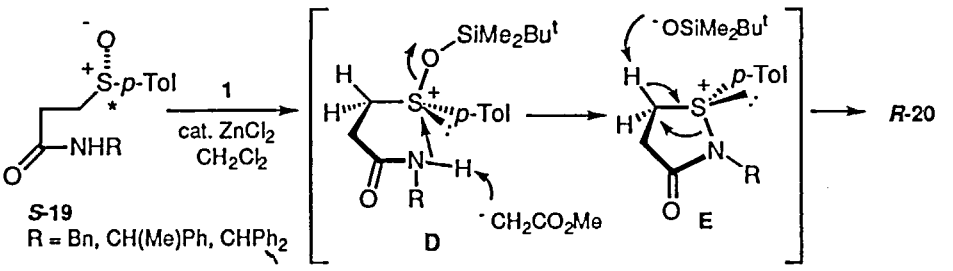



FIGURE 12 Plausible mechanism for the Pummerer-type cyclization of chiral, non-racemic β-amidosulfoxides.

The mechanism of penicillin biosynthesis from the Arnstein tripeptide (LLD-ACV) has been extensively studied and reviewed by many chemists. Most of the biosynthetic mechanisms have been ascertained by Baldwin using an excellent enzymatic technique.[30] However, the first step in the biosynthesis of penicillin, conversion of the Arnstein tripeptide to a *cis* β-lactam intermediate is still a fascinating mechanistic problem. Although Baldwin *et al.* recently proposed a mechanism involving an iron-bound thioaldehyde formation route via a Pummerer-type cyclization, the intermediate for this mechanism has not yet been identified. The mechanism of selective formation of the *cis*-β-lactam ring is still also unknown.[31] These types of biomimetic reactions have been chemically studied. An example of an unsuccessful intramolecular Pummerer cyclization of the sulfoxide (**21**) involving a cysteine moiety under standard Pummerer conditions was reported by Wolfe.[32] Although Kaneko reported the conversion of the very simple 3-phenylsulfinyl propionamide (**22**) into a β-lactam with TMSOTf / triethylamine,[33] a successful biomimetic synthesis of β-lactams from Arnstein tripeptide derivatives had not yet been carried out.

We examined our silicon-induced intramolecular Pummerer-type cyclization of the closely related Arnstein tripeptide analogs (23) with **1**, and found that *R*-23, when treated with **1** predominantly gave the *cis* -β-lactams (24), and *S*-23 with **1** gave a mixture of *cis* and *trans* 24.[34, 35] It is noteworthy that *cis* β-lactams were preferentially obtained from *R*-23 considering the fact that the 3-amino-β-lactam moiety of naturally occurring penicillins has a *cis* orientation. The present results provide useful information on the first key step in penicillin biosynthesis (Figure 13).

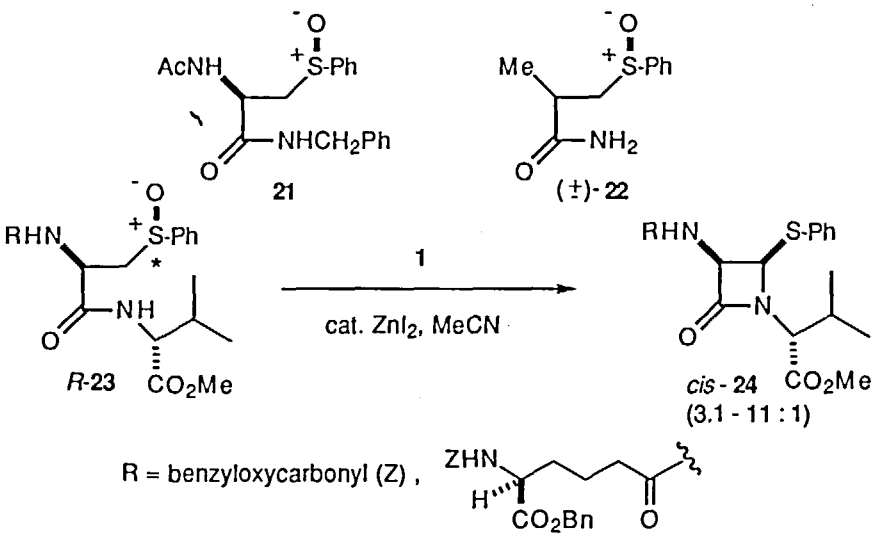



FIGURE 13 Pummerer-type cyclization of Arnstein tripeptide analogues.

## AROMATIC PUMMERER-TYPE REARRANGEMENTS

The treatment of aliphatic sulfoxides with acid anhydrides causes the Pummerer rearrangement which produces α-acyloxy sulfides. Because these products can be readily hydrolyzed to carbonyl compounds, the overall reaction provides a convenient method for the transformation of the sulfinyl group into the carbonyl group. If similar sequential reactions occur in *p*-sulfinylphenols, this could provide to be an effective method for the preparation of *p*-quinones. However, the possibility of such a reaction has never been elucidated. Only two related examples have been reported for the reaction of *p*-(methylsulfinyl)-[36] and *O*-(phenylsulfinyl)phenol.[37] These aromatic sulfoxides were reacted with acid

anhydrides to give the β.γ-unsubstituted sulfonium ions, to which nucleophiles were added at the γ-carbon of the sulfinyl group, giving the corresponding nucleophile-substituted sulfenylphenols. We found the first Pummerer-type rearrangement of *p*-sulfinylphenols **25** and **26**, which gave the corresponding *p*-quinones **27** and **28** in high yields.[38] Although the reaction of **25a** (R'=Ph) with 10 equiv. of acetic anhydride in refluxing 1,2-dichloroethane did not proceed at all, reaction of **25a** with 10 equiv. trifluoroacetic anhydride (TFAA) in methylene chloride occurred immediately at 0 °C. A 1:1 mixture of the dihydroquinone mono(trifluoroacetate) and the benzoquinone **27** was obtained directly and almost quantitatively. Treatment of this mixture with aqueous $NaHCO_3$ in MeOH at room temperature for 1 h caused hydrolysis of the trifluoroacetate and subsequent auto oxidation to give **27** in 84% yield. The present method was applicable to the sulfoxides **26** having one or two electron-withdrawing ester and amide groups. Their treatment with TFAA from -30 °C to room temperature gave 1:1 mixtures of the dihydroquinones and the quinones **28**, which were subjected to mild oxidation by $MnO_2$ to provide **28** in 61-90% yields (Figure 14).

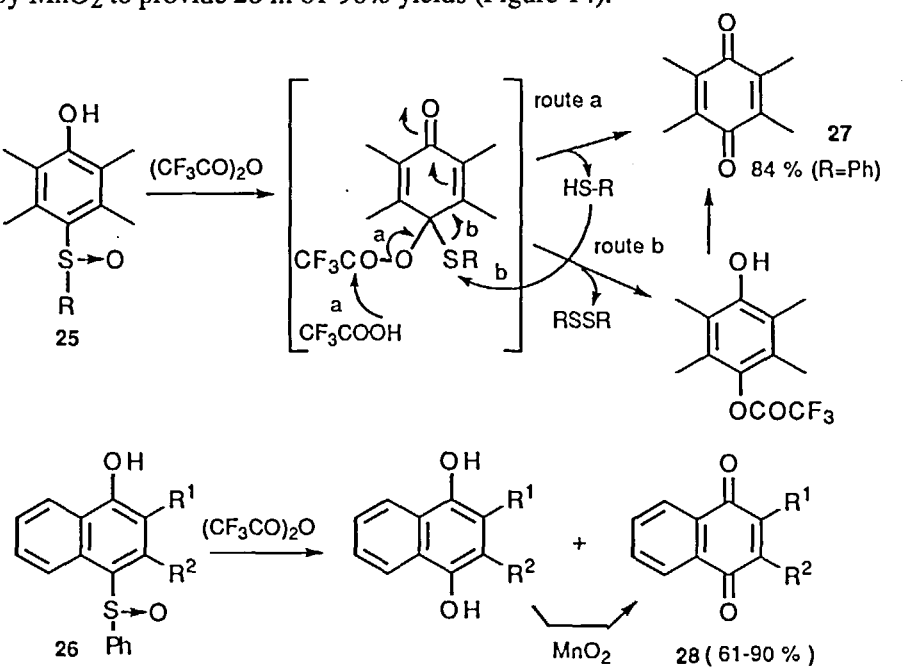



FIGURE 14 Pummerer-type rearrangement of *p*-sulfinylphenols.

*ipso*-Substitution of the suitably *para*-functionalized phenols by oxygen nucleophiles has been developed to give protected *p*-dihydroquinone derivatives, which are often used in the preparation of biologically active natural products. These methods, however, need relatively high temperature and/or strongly basic conditions, and they are, in some cases, inconsistent with carbonyl groups. We found a novel and mild preparation of protected *p*-dihydroquinone derivatives **30** through the direct *ipso*-substitution of the sulfinyl group of *p*-sulfinylphenyl ethers **28** into oxygen functional groups.[39] It was expected that the reaction of *p*-sulfinyl ethers **29** with TFAA would cause a Pummerer-type rearrangement on the sulfinyl group to give an electrophilic oxonium intermediate **F**, which would be predominantly attacked by the nucleophile at the sulfur atom to give the desired dihydroquinones.[30] For the success of this reaction, the $OR^1$ group must be efficiently electron-donating and the $OR^1$ bond must be stable in the intermediate **F**. Although the reaction of **29a** ($R^1$=Ac, $R^2$=Ph) with TFAA did not proceed even after 2 d at room temperature, a similar treatment of **29b** ($R^1$=Me, $R^2$=Ph) with TFAA was completed at 0 °C within 30 min to give the desired trifluoroacetoxy derivative **30b** (51% yield) accompanied by the reduced product **31b**. The reaction of **29c** ($R^1$=$SiBu^tMe_2$, $R^2$=Ph) produced **30c** in better yield (58%). Although the use of the electron-donating derivative **29d** ($R^1$=$SiBu^tMe_2$, $R^2$=$CoH_4$-*p*-OMe) instead of **29c** increased the yield of **30c** to 73% yield, we could not depress the formation of **31c** by changing the silyl groups and the $R^2$ groups.

It is thought that the attack of the trifluoroacetoxy anion on the sulfur atom of the intermediate **F** gives **30** and the sulfenyl trifluoroacetate [indeed, the addition of 3 equiv. of trifluoroacetic acid slightly improved the yield of **30**]; therefore, formation of **31** may be due to reaction of the sulfenyl trifluoroacetate with unreacted **29**. Therefore, we examined the *in situ* trapping and/or decomposition of the acetate. Although the addition of thiophilic compounds such as thiols and $P(OMe)_3$ did not work for this purpose, alkenes such as styrene or 3,3-dimethyl but-1-ene efficiently trapped the acetate to give a 98% yield of **30c** (Figure 15).

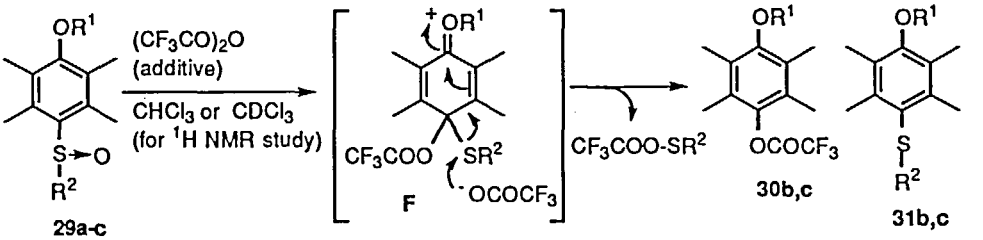
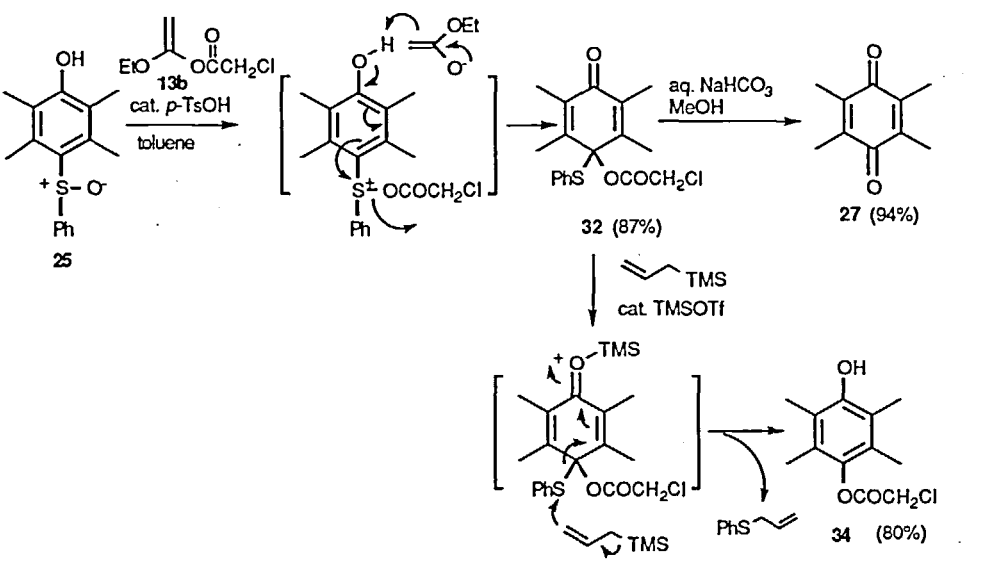



FIGURE 15 Pummerer-type rearrangement of *p*-sulfinylphenol derivatives.

Although all these Pummerer-type reactions may involve the quinone mono *O,S*-acetal intermediates **F**, these intermediates have never been isolated. It is probably due to the use of acid anhydrides as the acylating reagent because the reaction mixture becomes acidic as the reaction proceeds.

We now found that the first isolation of the *O,S*-acetals (**32,33**) by employing 1-ethoxyvinyl esters **13** for the Pummerer-type rearrangement of *p*-sulfinylphenols **25, 26**. Selective transformation of **32, 33** into both the quinones **27, 28** and the dihydroquinones **34** was also attained. This success is due to the feature of the ketene acetal reagent **13b**; that is, the reactions proceeds under nearly neutral conditions between room temperature and 60 °C releasing neutral and stable ethyl acetate as a single side product (Figure 16).



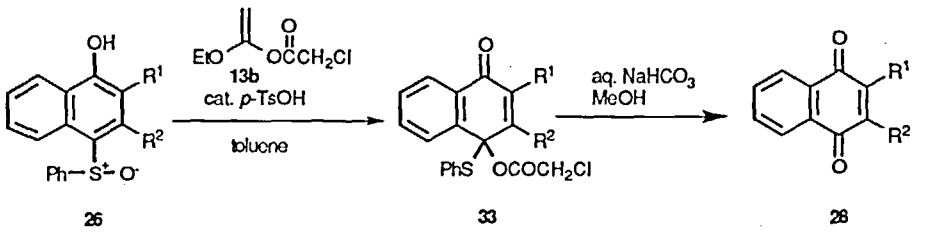



FIGURE 16 Isolation of Pummerer-type rearrangement intermediate *O,S*-acetals



In the *ipso*-substitution of the sulfinyl group of *p*-sulfinylphenyl silyl ethers **29** int acyloxy groups (Figure 15), the silyloxy group functioned as an efficient electror donating group to cause Pummerer-type rearrangement under mild conditions i high yields. We have now succeeded in extending this method to construc suitably protected dihydroquinones having neighboring hydroxy groups. Howeve an application of this method to a sulfoxide having 1-hydroxyalkyl side-chain wa unsuccessful. The use of the *O*-protected derivatives was not attainable, whic resulted in ready migration of the silyl group and complication in the Pummere type reaction. These difficulties were attributable to steric congestion for separat protection of the neighboring two hydroxy groups and/or easy decomposition an elimination of the benzylic functional groups.

These problems were clearly resolved by protection of both hydroxy groups b silylene formation. Thus, the treatment of the dihydroxy sulfide **35** wit $^{t}Bu_2Si(OTf)_2$ gave the silylene-protected sulfide, which was found to b sufficiently stable in $SiO_2$ chromatography and in the following transformation The oxidation of the sulfide with mCPBA below -30°C quantitatively gave th sulfoxide **36** in 80%-quantitative overall yield. The sulfoxide **36** was subjected t the Pummerer-type reaction producing the *p*-acetoxy product **37** in 70-97% yiel after acetylation. In a similar manner, the sequential silylene-protection c dihydroxynaphthalene sulfide **38** and the Pummerer-type reaction of its sulfoxid **39** provided the *peri*-hydroxy dihydroquinone **40**, which is readily convertible t the naphthoquinone derivative **41**[40](Figure17).

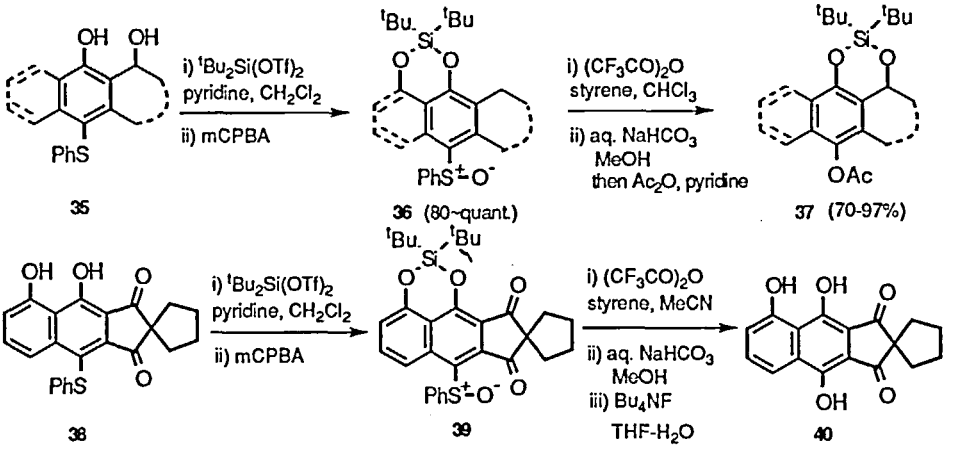



FIGURE 17 Pummerer-type reaction of silylene-protected sulfoxides.

Thus, the presented procedure features ready formation of the silylene protective group, good overall yields, mild reaction conditions, and the formation of suitably protected dihydroquinones having *peri*-hydroxy groups, which would afford a novel and promising methodology for total synthesis of naturally occurring *peri*-hydroxy polyaromatic quinones, such as fredericamycin A[41] (Figure 18).

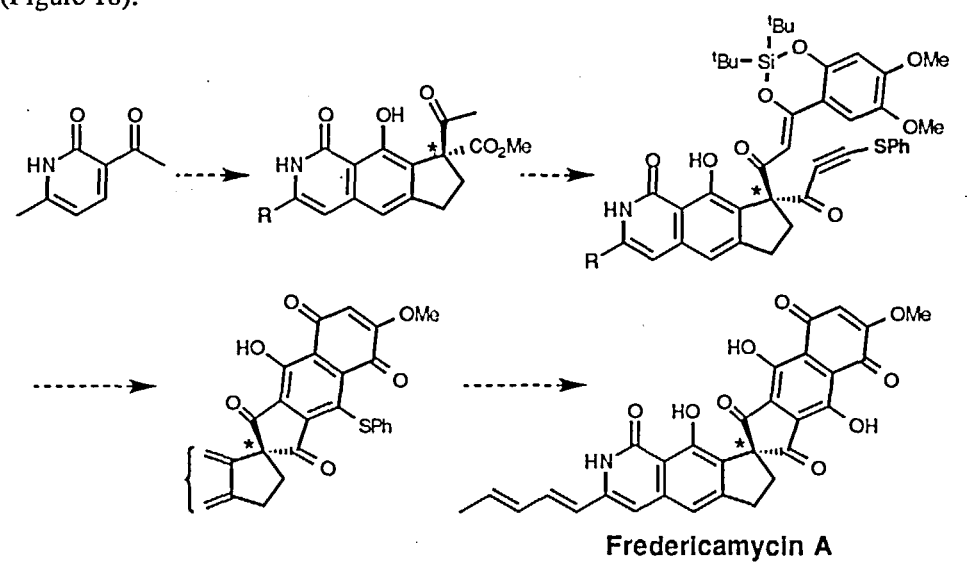



FIGURE 18 Synthetic approach to optically active fredericamycin A.

## CONCLUSIONS

This review has attempted to summarize some of our recent advances in Pummerer-type rearrangements. The use of silyl and acyl transfer reactions of ketene acetal derivatives utilizing enol-keto transformation[9] has allowed the development of highly enantioselective Pummerer-type rearrangement of chiral, non-racemic sulfoxides and the isolation of the intermediates of aromatic Pummerer-type rearrangement of *p*-sulfinylphenol derivatives. Finally, it should be mentioned that these reactions proved to be powerful for synthesing useful organic compounds including optically active natural products.

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