heating period, the sample was concentrated to dryness. The NMR ($CDCl_3$) spectrum was identical with that reported above for **8**.

A 8-mg sample of minor adduct **10** was heated in CD_3CO_2D at 100 °C for 20 min. The NMR spectrum showed partial exchange at C-10 had occurred (d of d at δ 3.22). An additional 25 min at 100 °C caused complete exchange at C-10. The sample was evaporated to dryness, redissolved in HOAc, heated for 25 min at 100 °C, and the reevaporated to dryness. The NMR spectrum in $CDCl_3$ of the residue showed a mixture of starting **10** and a new isomer **12**, with characteristic signals at δ 3.28 (t, J = 8), 5.25 (br s), 5.57 (d, J = 6), and 5.69 (br s).

2-Acetamido-6-methyl-8β-acetoxy-9β-[(phenylthio)-acetyl]-3,4,5,8,9,10β-hexahydroquinazolin-4-one (19) and 2-Acetamido-6-[1-hydroxy-2-(phenylthio)-2-acetylvinyl]-4-(1*H*)-pyrimidinone (22, Tentative Assignment). A mixture of diene **7** (1.56 g, 12.4 mmol), pyrimidinone **16**[1] (1.50 g, 4.96 mmol) as a yellow foam, and THF (20 mL) was placed in a Parr pressure reactor and heated at 150 °C for 46 h. The resulting dark brown solution was concentrated, and the residue was triturated with pentane (discarded). Then the residue was dissolved in EtOAc and filtered through silica gel (1.5 g), giving 1.99 g of a brown semisolid. This was dissolved in benzene and placed on a reflux–recycle column of silica gel. Continuous elution with benzene for 2.5 h, benzene–EtOAc (97:3) for 2.5 h, and then benzene–EtOAc (95:5) for 2.5 h gave a total of 556 mg of R_f 0.66 (EtOAc) materials as a yellow oil which was discarded. Elution with benzene–EtOAc (9:1) for 1.6 h gave **19** (221 mg, R_f 0.56) as a yellow foam. Crystallization from EtOAc–hexanes gave **19** (121 mg) as pale yellow crystals, mp 212–214 °C. The analytical specimen was obtained by recrystallization from the same solvent: mp 217 °C; NMR (acetone-d_6) δ 1.79 (br s, 3), 1.86 (s, 3), 2.10 (s, 3), 2.2–2.5 (m, 2), 3.24 (d of d, 1), 3.60 (d, 1), 4.07 (d, 1), 5.40 (br d, 1), 5.56 (m, 1, vinyl), 7.2–7.3 (m, 5). Anal. Calcd for $C_{21}H_{32}N_3O_5S$: C, 58.73; H, 5.40; N, 9.78. Found: C, 58.98; H, 5.20; N, 9.46.

Continued elution of the column with benzene–EtOAc (9:1) for 2 h brought down a yellow foam (290 mg) consisting of 3 spots, R_f 0.56 (**19**), 0.44 (minor isomer), and 0.32 (**22**). Crystallization from EtOAc–hexanes gave 25 mg of major adduct **19** (total yield, 7%) but the minor isomer could not readily be obtained in pure form. A further elution of the column gave side product **22** (412 mg, 28%). Crystallization from EtOAc–hexanes gave the analytical specimen: mp 202–203 °C; NMR δ 2.22 (s, 3), 2.30 (s, 3), 6.02 (s, 1), 7.4 (m, 5). Anal. Calcd for $C_{16}H_{15}N_3O_4S$: C, 55.64; H, 4.38; N, 12.17. Found: C, 55.59; H, 4.19; N, 12.27.

2-Acetamido-6-methyl-8β-acetoxy-9β-(acetoxyacetyl)-3,4,5,8,9,10β-hexahydroquinazolin-4-one (20). The pressure reactor was charged with acetoxy dienophile **17**[1] (150 mg, 0.59 mmol), diene **7** (163 mg, 1.29 mmol), and THF (10 mL), sealed, and heated at 155 °C for 48 h. The resulting brown solution was concentrated, leaving a brown oil (315 mg). Preparative TLC over silica gel (EtOAc) gave four bands. The third band from the bottom yielded 17 mg (8%) of crude adduct **20**. Two recrystallizations from EtOAc gave **4** mg of the pure specimen: mp 218.5–219.5 °C; NMR δ 1.76 (br s, 3), 2.04 (s, 3), 2.12 (s, 3), 2.16 (s, 3), 2.2–2.4 (m, 2), 3.21 (d of d, 1), 4.92 (AB system, 2), 5.56 (m, 2, H-8 and vinyl); MS, m/e (relative intensity) 379.139 (1, calcd for $C_{17}H_{21}N_3O_7$, 379.138), 320 (1), 296 (5), 254 (100).

2-Pivalamido-6-methyl-8β-acetoxy-9β-(acetoxyacetyl)-3,4,5,8,9,10β-hexahydroquinazolin-4-one (21). The pressure reactor was charged with acetoxy dienophile **18** (3.25 g, 11.0 mmol), diene **7** (3.02 g, 24.0 mmol), butylated hydroxytoluene (20 mg) and THF (50 mL), sealed, and heated at 170 °C for 90 h. The resulting tan solution was concentrated and triturated with pentane. The insoluble solid was dissolved in $CHCl_3$, and silica gel (6 g, 60–200 mesh) was added. The solvent was removed, and the residue was layered on top of a 2 × 15 cm column of silica gel in a reflux–recycle column. Elution with benzene for 18 h gave 1.5 g of crude material which was chromatographed again as above. Elution with EtOAc–hexanes (1:4) gave fractions which were a single spot (R_f 0.3; EtOAc–hexanes, 1:1). These were combined, affording 148 mg of crude **21** from which 100 mg (2%) of **21** was obtained as white crystals by crystallization from EtOAc-hexanes: mp 162–163 °C; NMR δ 1.26 (s, 9), 1.76 (s, 3), 2.04 (s, 3), 2.12 (s, 3), 2.15–2.60 (m, 2), 3.16 (br d of d, 1), 4.84 and 4.92 (AB, 2), 5.46 (br d, 1, H-9), 5.60 (br d, 1). Anal. Calcd for $C_{20}H_{27}N_3O_7 \cdot 1.5\ H_2O$: C, 57.02; H, 6.24; N, 8.67. Found: C, 56.94; H, 5.98; N, 8.90.

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Registry No. **1**, 4368-28-9; **2**, 86944-21-0; **3**, 86993-48-8; **4**, 87011-53-8; **5** (isomer 1), 86970-97-0; **5** (isomer 2), 86971-08-6; **6** (isomer 1), 86970-98-1; **6** (isomer 2), 86971-09-7; **7**, 17616-47-6; **8**, 86970-99-2; **9**, 86971-00-8; **10**, 87037-51-2; **11**, 87037-52-3; **13**, 86971-01-9; **13** osmate ester, 86971-07-5; **14**, 86971-02-0; **15**, 87067-99-0; **15** osmate ester, 87037-53-4; **16**, 86944-30-1; **17**, 86944-42-5; **18**, 86944-43-6; **19**, 86971-03-1; **20**, 86971-04-2; **21**, 86971-05-3; **22**, 86971-06-4; 1,3-butadiene, 106-99-0; isoprene, 78-79-5.

Supplementary Material Available: Tables I–VI containing final fractional coordinates, molecular dimensions, and anistropic temperature factors for X-ray analysis of **11** and **14**·H_2O (14 pages). Ordering information is given on any current masthead page.

Diastereoselective α Allylation of Secondary and Tertiary Thioamides via Thio-Claisen Rearrangement. A Structural Proof of *Z* Secondary Thioamide Dianions and *Z* Tertiary Thioamide Anions[1a,b]

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Highly diastereoselective α allylation of secondary and tertiary thioamides is achieved by making use of thio-Claisen rearrangement. From the correlation between the diastereoselectivities in products and the structures of allylating agents, the *Z* structures of secondary thioamide dianion (~100% *Z*) and tertiary thioamide anion (>97% *Z*) are concluded.

The studies on the structures of organometallics and the stereochemical outcome of the reactions with these reagents have been the subject of continuing interest. Particularly the methodology based on the enolate chemistry

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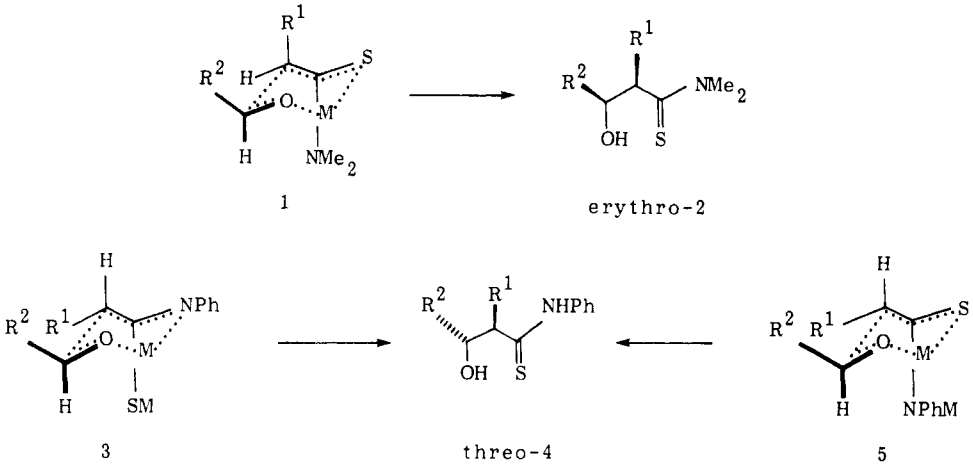
Scheme I



has made a pivotal contribution to the regio-,[2] stereo-, and enantioselective C–C bond-forming reactions.[3]

Recently we have disclosed that tertiary thioamide anions react with aldehydes to provide erythro aldols selectively.[1a] Although there have been reported few exceptions,[4] it is generally accepted that the aldol condensation proceeds via a six-membered chairlike transition state, **1**, with an aldehyde substituent in an equatorial orientation[5] (Scheme I). On the basis of this assumption, the *Z* structure of the tertiary thioamide anions was proposed.[1a]

In sharp contrast to this, the secondary thioamide dianions reacted with aldehydes to furnish threo aldols in high selectivity.[1b] This stereochemical outcome suggests that high geometric purity of these dianions but tells us nothing about the stereochemistry of these anions, because both the *Z* and *E* dianions might furnish the threo aldols, provided that there is a selective coordination of an aldehyde oxygen either to the metal counterion bound to a nitrogen atom (transition state **3**, *Z* dianion) or to the metal counterion bound to a sulfur atom (transition state **5**, *E* dianion).

The purpose of this paper is to describe the details of our study on the thio-Claisen rearrangement via the tertiary thioamide anion and the secondary thioamide dianion,[6] which was undertaken to determine the structures of these anions. Preliminary accounts of this subject have appeared.[1a,b]

Results and Discussion

The most convenient and direct method to obtain the information about the structures of enolates (*E* or *Z*) in solutions might be based on the comparison of the ^1H and/or ^{13}C NMR spectra of both stereoisomers of these anions.[7] However, in sharp contrast to other carbonyl compounds,[8] both the secondary and tertiary thioamides selectively provide only one stereoisomer of enolates, irrespective of reaction conditions [i.e., kinetic and thermodynamic: variations of temperatures from −78 to +65 °C, order of addition (addition of a base to thioamide and the reverse), kinds of bases (*n*-butyllithium, *sec*-butyllithium, isopropylmagnesium bromide, lithium isopropylamide), and kinds of solvents or cosolvents (Et_2O, THF, tetramethylethylenediamine, hexamethylphosphoric triamide)]. Moreover, these anions are structurally equivalent to trisubstituted olefins, two of the three substituents being constituted of heteroatoms. These situations might render a rigorous structural determination of thioamide anions based on the NMR techniques impractical.

The stereoselective formation (≥95%) of tertiary thioamide enolates was first noted by Brandsma et al.[9] They obtained (*E*)-ketene *S,N*-acetals selectively by an alkylation of anions, generated from tertiary thioamides by treatment with KNH_2 in liquid NH_3. The *E* structure was determined on the basis of systematic investigation of the chemical shifts of the vinylic protons of both stereoisomers of ketene *S,N*-acetals in the ^1H NMR spectra. Furthermore, we reported previously a stereoselective α,α'-coupling reaction of tertiary thioamides, and the selectivity was explained by invoking the *E* structure of tertiary enolates, generated by treatment with *sec*-BuLi in THF.[10] These argue against the conclusion deduced from the aldol con-

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(4) For aldol condensation of a zirconium enolate and an enolate with a counterion with no chelating ability, an acyclic, a pseudochair, or a boat transition state is proposed: (a) Evans, D. A.; McGee, L. R. *Tetrahedron Lett.* **1980**, *21*, 3975. (b) Yamamoto, Y.; Maruyama, K. *Ibid.* **1980**, *21*, 4607. (c) Noyori, R.; Nishida, I.; Sakata, J. *J. Am. Chem. Soc.* **1981**, *103*, 2016. See also ref 3e.

(5) (a) Bartlett, P. A. *Tetrahedron* **1980**, *36*, 2. (b) Mukaiyama, T. *Org. React.* **1982**, *28*, 203.

(6) For thio-Claisen rearrangement via *S*-allyl onium salts, see: (a) Takano, S.; Hirama, M.; Araki, T.; Ogasawara, K. *J. Am. Chem. Soc.* **1976**, *98*, 7084. (b) Gompper, R.; Ulrich, W.-R. *Angew Chem.* **1976**, *88*, 300. (c) Tamaru, Y.; Harada, T.; Yoshida, Z. *J. Am. Chem. Soc.* **1980**, *102*, 2392. (d) Tamaru, Y.; Mizutani, M.; Furukawa, Y.; Kitao, O.; Yoshida, Z. *Tetrahedron Lett.* **1982**, *23*, 5319.

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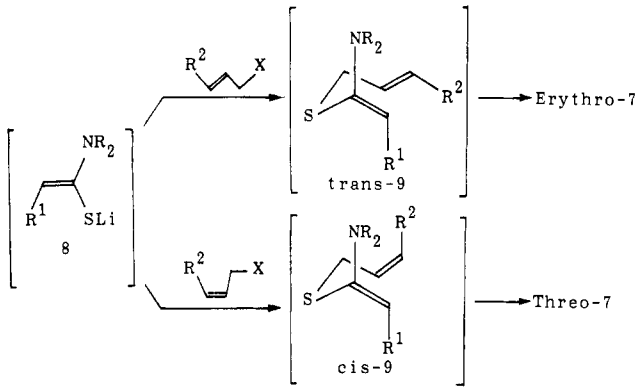
(10) Tamaru, Y.; Harada, T.; Yoshida, Z. *J. Am. Chem. Soc.* **1978**, *100*, 1923.

Table I. Diastereoselective α Allylation of Tertiary Thioamides via Thio-Claisen Rearrangement[a]

entry	thioamide 6	R¹	R²	R³	allylating agent[b] stereo	R⁴	X	product	yield,[c] %	ratio[d] of *erythro*-7/*threo*-7
1	6a	Me	Me	Me	trans	Me	OTs	7a	42[e]	97:3 (96:4)
2	6a	Me	Me	Me	cis	Me	OTs	7a	55	3:97 (1:99)
3	6a	Me	Me	Me	trans	Me	Br	7a	80	86:14 (88:12)
4	6a	Me	Me	Me	trans	Ph	OTs	7b	45	95:5 (100:0)
5	6a	Me	Me	Me	trans	CH_2OSiMe_3	Cl	7c	43	8:92[f] (9:91)
6	6a	Me	Me	Me	cis	CH_2OSiMe_3	Cl	7c	42	90:10[f] (91:9)
7	6b	Me	$CH(Me)_2$	$CH(Me)_2$	trans	Me	OTs	7d	94	98:2 (96:4)
8	6b	Me	$CH(Me)_2$	$CH(Me)_2$	cis	Me	OTs	7d	82	22:78 (1:99)
9	6c	$CH(Me)_2$	Me	Me	trans	Me	Br	7e	80	50:50 (88:12)
10	6c	$CH(Me)_2$	Me	Me	trans	Me	OTs	7e	38	50:50 (96:4)
11	6d	Ph	Me	Me	trans	Me	OTs	7f	63	95:5 (96:4)
12	6d	Ph	Me	Me	cis	Me	OTs	7f	55	12:88 (1:99)
13	6d	Ph	Me	Me	trans	Ph	OTs	7g	92	93:7 (100:0)
14	6e	$-(CH_2)_2-$		Me	trans	Me	Br	7h	83	38:62 (12:88)
15	6e	$-(CH_2)_2-$		Me	trans	Ph	Br	7i	89	*g*
16	6f	$-(CH_2)_3-$		Me	trans	Me	Br	7j	85	31:69 (12:88)

[a] For the structures of 6, 7, and the allylating agents, see eq 1. All the reactions, except for entries 5 and 6, were performed under the conditions indicated in eq 1. For entries 5 and 6, the Claisen rearrangement was undertaken at an ambient temperature for 2 days. [b] The stereo- (and regio-) chemical purity of allylating agents employed in these experiments is as follows: *trans*-crotyl alcohol (trans 96.4%, cis 3.6%), *cis*-crotyl alcohol (cis 99%, trans 1%), *trans*-4-(trimethylsiloxy)-2-butenyl chloride (trans 90.6%, cis 9.4%), *cis*-4-(trimethylsiloxy)-2-butenyl chloride (cis 90.9%, trans 9.1%), *trans*-crotyl bromide (trans ca. 70%, cis ca. 10%, α-methallyl bromide ca. 20%), *trans*-cinnamyl bromide (100%), *trans*-cinnamyl alcohol (100%). [c] Yield refers to the combined isolated yield of *erythro*-7 and *threo*-7 (and their regioisomer in entry 15). [d] The values in parentheses refer to the expected ratios based on the stereochemical purities of allylating agents. [e] In addition to 7a was obtained a regioisomer, *N,N*-dimethyl-2-methylthiohex-4-enamide, in 6% yield. [f] The ratio was calculated from the ratio of 17 (Scheme IV). [g] The product consists of ca. 70% of *N*-methyl-3-(*trans*-cinnamyl)pyrrolidine-2-thione and ca. 30% of *erythro*- and *threo*-*N*-methyl-3-(1-phenyl-2-propenyl)pyrrolidine-2-thione (7i).

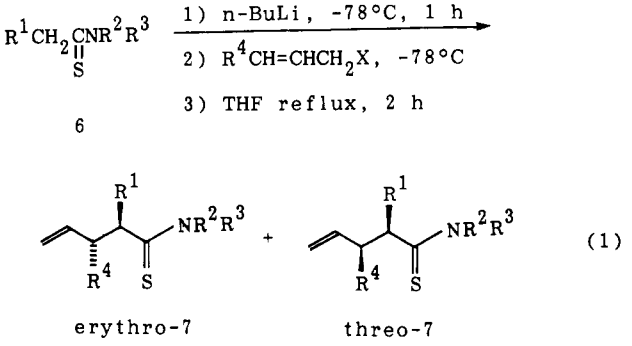
Scheme II



densation of tertiary thioamides (vide supra).[1a]

So that the structures and the stereochemical purities of secondary thioamide dianions and tertiary thioamide anions could be determined, we examined the thio-Claisen rearrangement, because it is well documented experimentally[11] and theoretically[12] that the (thio) Claisen rearrangement proceeds preferentially through a six-membered chairlike transition state, and hence the stereoselectivities in the rearranged products can be nicely correlated to the structures and structural purities of allyl vinyl ethers (or sulfides). Allyl vinyl sulfides with the requisite molecular framework may be easily set up by a selective alkylation at the sulfur atom of thioamide anions with stereochemically defined allylating agents. An especially desirable feature of this technique is based on its neutral (or basic, if any) reaction conditions, under which isomerization of *S*-allylketene *S,N*-acetals might be minimized.[6c,9b,13]

Diastereoselective α Allylation of Tertiary Thioamides. The present α allylation of tertiary thioamides consist of the following three steps, which can be performed in one pot (eq 1): (a) generation of an enolate of



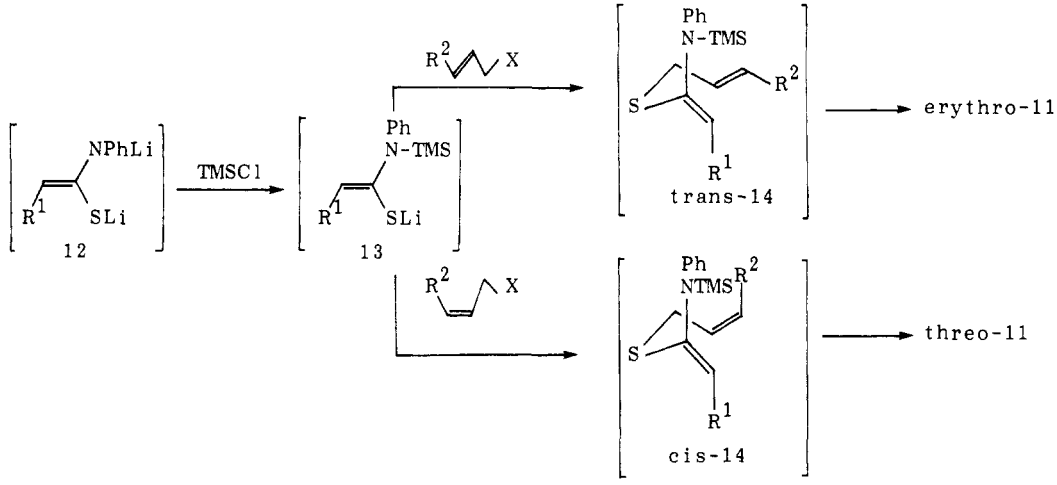
teritary thioamide by treatment with 1.1 equiv of *n*-BuLi (at −78 °C for 1 h in tetrahydrofuran), (b) S-alkylation with a proper cis or trans allylating agent (at −78 °C for 0.5 h and then at room temperature for 0.5–1 h), and (c) thio-Claisen rearrangement (mostly at the temperature of refluxing THF for 2 h). Results were summarized in Table I. As allylating agents, allylic bromides furnished the α-allylated tertiary thioamide 7 in better yields than the corresponding tosylates, but mainly due to the difficult availability of allylic bromides in high regio- and stereochemical purity and low regioselectivity in the S-allylation process (allylic inversion, entry 15, Table I), we mostly

(11) For comprehensive reviews, see: (a) Rhoads, S. J.; Rauling, N. R. *Org. React.* **1975**, *22*, 1. (b) Bennett, G. B. *Synthesis* **1977**, 589. (c) Ziegler, F. E. *Acc. Chem. Res.* **1977**, *10*, 227.

(12) Fleming, I. "Frontier Orbitals and Organic Chemical Reactions"; Wiley: New York, 1976; Chapter 4-1-3.

(13) The low stereochemical purity of the enolate generated from thioisovaleramide is apparent from the following observations. (1) The reaction of this enolate with methyl iodide provides a ca. 2:1 mixture of ketene *S,N*-acetals. No significant change of the ratio after THF refluxing for 3 h indicates that ketene *S,N*-acetals do not isomerize under the conditions employed for the thio-Claisen conditions. (2) The reaction of this enolate with aldehydes provides threo aldols in poor selectivities, while the same reaction with the enolate, generated by a 1,4-addition of MeLi or MeMgBr to *N,N*-dimethylthiocrotonamide, provides threo aldols in high selectivities. Details of this aldol reaction with be reported in due course.

Scheme III



employed tosylates, which were prepared in situ by the reaction of lithium salts of allylic alcohols and toluenesulfonyl chloride in THF at −78 °C. The diastereoselectivity of **7** was determined on the bases of the area intensities in HPLC, VPC, and ^1H and/or ^{13}C NMR spectra.

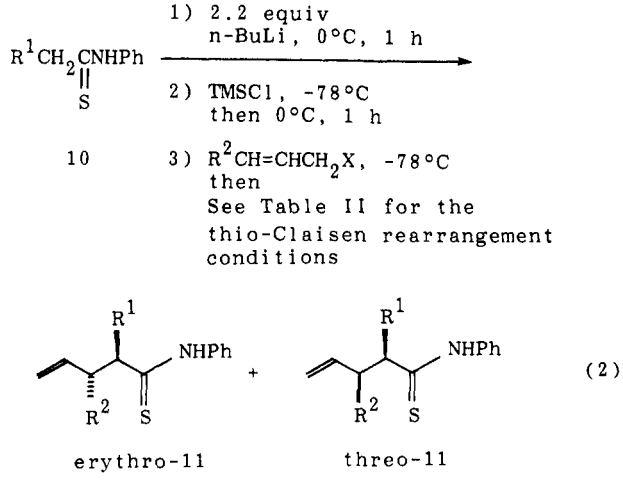
As seen from Table I, trans- and cis-allylating agents provide *erythro*- and *threo*-**7**, respectively, in high selectivities. These results apparently establish the *Z* structure of tertiary thioamide enolates **8** (Scheme II). The reversed assignment of structures of **7h** and **7j** (entries 14 and 16) is due to an inherent *E* geometry of *N*-methylthiopyrrolidone and *N*-methylthio-δ-valerolactam enolates.

On the basis of the two pairs of results in entries 1,2 and 5,6, the stereochemical purity of enolate **8a** (R = R^1 = Me) derived from *N,N*-dimethylthiopropionamide might be estimated to be more than 97%, because the most parts of the wrong diastereomers might be attributed to the stereochemical impurities of allylating agents employed in these runs (*trans*-crotyl alcohol, 96% trans, 4% cis; *cis*-crotyl alcohol, cis 99%, trans 1%; *trans*-4-(trimethylsiloxy)-2-butenyl chloride, trans 90.6%, cis 9.4%; *cis*-4-(trimetylsiloxy)-2-butenyl chloride, cis 90.9%, trans 9.1%). *N,N*-Dimethylphenylthioacetamide (**6d**) was allylated to give rise to α-allylated thioamides **7f** and **7g** in similarly high diastereoselectivities (entries 11–13).

Unexpectedly low diastereoselectivities in entries 8–10 and 14–16 seem to deserve some comments. In comparison with the result in entry 7, the diminished selectivity in the allylation of *N,N*-diisopropylthiopropionamide (**6b**) with *cis*-crotyl tosylate (entry 8) might find its origin on a severe pseudo-1,3-diaxial interaction in transition state *cis*-**9** (R = isopropyl, R^1 = R^2 = methyl, Scheme II). Among the thioamides examined, thioisovaleroamide (**6c**) is only one exception which provides an enolate in poor stereoselectivity, the *Z*/*E* ratio being estimated to be 2:1.[13] This seems to be reflected in part in the low selectivities in entries 9 and 10. Furthermore, a severe pseudogauche interaction between the isopropyl and methyl groups in a transition state, *trans*-**9**, might cooperate to cause a complete disappearance of selectivity in **7e**. The low selectivity in entries 14–16 might be attributed to an epimerization of *threo*-**7h** and **7j**, because it was noted that these thiolactams were exceptionally prone to undergo a base-catalyzed epimerization.[6d] So far as the α allylation of thiolactams is concerned, the method utilizing *S*-alkyl onium salts seems to be superior to the present enolate method.[6d]

Finally, an α alkylation of a tertiary thioamide was conducted under Brandma's conditions[9] in order to get rid of the inconsistency in the stereochemical assignment of tertiary thioamide enolates mentioned previously in this paper: thioamide **1a** was treated with 1.2 equiv of sodium amide in liquid ammonia and then with 1.5 equiv of *trans*-crotyl bromide to provide *erythro*-**7a** and *threo*-**7a** in a 73:27 ratio (cf. entry 3, Table I). Although the diastereoselectivity is rather lower than the expected value (88:12, based on the stereochemical purity of crotyl bromide), and the reason for of this is unclear at present, the erythro selection clearly supports the *Z* structure of enolate generated under the Brandma's conditions, and hence the previous assignment should be corrected.[9,10]

Diastereoselective α Allylation of Secondary Thioamides. The dianions **12**, generated from *N*-phenyl thioamides **10a** (R^1 = Me) and **10b** (R^1 = Ph) by treatment with 2.2 equiv of *n*-butyllithium (0 °C, 1 h, in THF), react with 1 equiv of alkyl halides selectively at the carbon atom α to the thiocarbonyl group to provide the α-alkylated secondary thioamides,[14] while they reacted selectively at the nitrogen atom with 1 equiv of trimethylsilyl chloride to furnish **13**, a structural equivalent of a tertiary thioamide enolate, which is then alkylated selectively at the sulfur atom to give rise to ketene *S,N*-acetals **14** (Scheme III). Accordingly the structure of dianion **12** might be



determined in a manner similar to the case of tertiary thioamide enolates, provided that the N-silylation proceeds without structural change of **12**.[15]

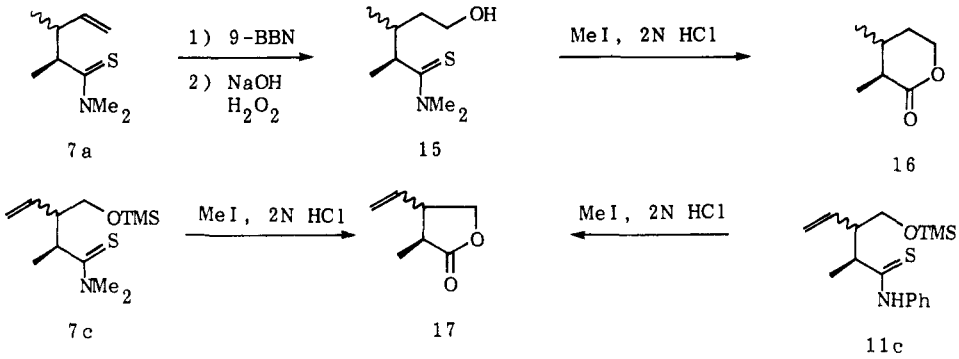
(14) Tamaru, Y.; Kagotani, M.; Furukawa, Y.; Amino, Y.; Yoshida, Z. *Tetrahedron Lett.* **1981**, *22*, 3413.

Table II. Stereospecific α Allylation of Secondary Thioamides via Thio-Claisen Rearrangement[a]

entry	thioamide no.	thioamide R^1	allylating agent[b] stereo	allylating agent[b] R^2	allylating agent[b] X	conditions[c]	product	yield,[d] %	product ratio[e] of *erythro*-11/*threo*-11
1	10a	Me	trans	Me	OTs	rt, 40 h	11a	51	99:1 (96:4)
2	10a	Me	cis	Me	OTs	rfl, 32 h	11a	50	1:99 (1:99)
3	10a	Me	trans	Ph	Br	rfl, 30 h	11b	56	99:1 (100:1)
4	10a	Me	trans	CH_2OSiMe_3	Cl	rt, 22 h	11c	53	10:90 (9:91)
5	10a	Me	cis	CH_2OSiMe_3	Cl	rfl, 12 h	11c	53	91:9 (91:9)
6	10b	Ph	trans	Me	OTs	rfl, 5 h	11d	44	99:1 (96:4)
7	10b	Ph	cis	Me	OTs	rfl, 19 h	11d	42	1:99 (1:99)
8	10b	Ph	trans	Ph	Br	rfl, 19 h	11e	73	99:1 (100:0)

[a] For the structures of 10, 11, and the allylating agents, see eq 2. [b] For the stereochemical purity of allylating agents, see footnote *b* in Table I. [c] For the conditions of anion generation and alkylation, see eq 2. The conditions shown in this column are for the Claisen rearrangement: rt = room temperature; rfl = reflux. [d] Yield refers to the combined isolated yield of *erythro*-11 and *threo*-11. [e] Ratio was determined by means of VPC, HPLC, and ^1H and/or ^{13}C NMR. The values in parentheses refer to the expected ratios based on the stereochemical purities of allylation agents.

Scheme IV



The alkylation of N-silylated enolate **13** with an appropriate cis- or trans-allylating agent and the following thio-Claisen rearrangement proceeded very cleanly and provided the α-allylated secondary thioamides **11** in very high diastereoselectivities. The N-protecting trimethylsilyl group was removed spontaneously during an aqueous workup. Results together with the rearrangement conditions were summarized in Table II. For the selective N-silylation, the phenyl substituent on the nitrogen atom seems to be essential. *N*-Methyl analogues provided either an intractable mixture of products or the expected products in very low yields. For example, the reaction of *N*-methylthiopropionamide with *trans*-crotyl tolylate provided an erythro–threo mixture (97:3) of *N*-methyl-2,3-dimethylthiopent-4-enamide in 13% isolated yield under the same conditions as for entry 1 (Table II). In these cases no improvement in yields was observed by employing diphenylmethylsilyl chloride in place of trimethylsilyl chloride.

Compared with **9**, the rearrangement of **14** was rather sluggish and required prolonged reaction times, especially in those cases where cis-allylating agents were employed. The reaction in entry 1 attained completion after 40 h at ambient temperature, while the reaction in entry 2 did not proceed to any appreciable extent under the same conditions, and an aqueous workup provided an intractable mixture of products. For completion of the reaction, the reaction mixture was refluxed for as long as 32 h. Despite the rather drastic conditions, no depression of diastereoselectivity was observed, and hence the other reactions were performed uniformly at the temperature of refluxing THF.

Interestingly, in entries 1 and 6 the diastereoselectivities of **11a** and **11d** apparently exceeded the stereochemical purity of *trans*-crotyl alcohol. These results might be rationalized as a result of a kinetic selection of *trans*-crotyl tosylate in the S-alkylation process. In the other cases in Table II the stereochemical purities of allylating agents were completely transferred to the diastereoselectivities in **11**. The stereospecific nature of the present reaction clearly indicates the complete stereochemical homogeneity of *Z* secondary thioamide dianions.

Although it is premature to discuss in detail why secondary thioamide dianions show the higher *Z* homogeneity than tertiary thioamide anions, these *Z* selectivities may be explained on the bases of an A(1,3) strain[16] between the substituents on the nitrogen atom and on the carbon atom α to the thiocarbonyl group in the conformers leading to the *E* anions.[17]

Structural Determination of Diastereomers 7 and 11. The stereochemistry of *erythro*- and *threo*-**7a** was determined by converting them to the corresponding amides (10 equiv of MeI, 2 equiv of K_2CO_3 in aqueous THF at room temperature, overnight, 89–91%) and by comparing their ^1H NMR and IR spectra with those of authentic samples.[18] A further confirmation was obtained by the transformation of *erythro*- and *threo*-**7a** into *cis*- and *trans*-2,3-dimethyl-δ-valerolactones (**16**), respectively, via hydroboration (1.1 equiv of 9-BBN in THF at room temperature and then $NaOH–H_2O_2$ at 0 °C; *erythro*-**15**

(15) In a strict sence we are unable to preclude the minor possibility of isomerization of the dianion **12** during silylation. However, there are many precedents which indicate that trimethylsilylation of enolates proceeds without stereochemical loss. (a) Ireland, R. E.; Mueller, R. H.; Willard, A. K. *J. Am. Chem. Soc.* **1976**, *98*, 2868. (b) Chan, T. H.; Aida, T.; Lau, P. W. K.; Gorys, V.; Harpp, D. N. *Tetrahedron Lett.* **1979**, 4029.

(16) (a) Johnson, F. *Chem. Rev.* **1968**, *68*, 375. (b) Hart, D. J. *J. Am. Chem. Soc.* **1980**, *102*, 397 and his extensive current works. (c) Wilsen, S. R.; Missa, R. N. *J. Org. Chem.* **1980**, *45*, 5079. (d) Overman, L. E.; Yokomitsu, T. *Ibid.* **1980**, *45*, 5229.

(17) See footnote 12 in ref 1a.

(18) Sucrow, W.; Richter, W. *Chem. Ber.* **1971**, *104*, 3679.

(55%), *threo*-**15** (74%)) followed by lactonization (10 equiv of MeI, 2 N HCl in aqueous THF at room temperature; *cis*-**16** (57%), *trans*-**16** (32%), Scheme IV).

The structural assignment of **16**, inter alia, rests on the NMR spectroscopies. The cis isomer showed a smaller vicinal coupling constant ($J_{C(2)H-C(3)H}$ = 6.0 Hz for *cis*-**16** and 9.0 Hz for *trans*-**16** in CCl_4) in the ^1H NMR spectra[19] and higher field resonances of two methyl groups (12.5 and 16.6 ppm for *cis*-**16** and 14.5 and 20.4 ppm for *trans*-**16**) in the ^{13}C NMR spectra[20] as compared with those of the trans isomer.

The structures of **7c** and **11c** were determined as follows: from *erythro*-**7c** and *erythro*-**11c** was obtained *cis*-2-methyl-3-vinyl-γ-butyrolactone (**17**) in 83% and 53% yields, respectively, by exposing each of them to excess MeI–2 N HCl in aqueous THF at ambient temperature. Similarly, *trans*-**17** was obtained in 65% and 49% yields by the similar lactonization of *threo*-**7c** and *threo*-**11c**, respectively. Also in this case, the cis isomer showed a smaller vicinal coupling constant[21] ($J_{C(2)H-C(3)H}$ = 8.8 Hz for *cis*-**17** and 12.0 Hz for *trans*-**17**) in the ^1H NMR spectra and a higher field resonance of methyl group (10.8 ppm for *cis*-**17** and 12.8 ppm for *trans*-**17**) in the ^{13}C NMR spectra as compared with those of the trans isomer. A further support was obtained by an epimerization of *cis*-**17** to a mixture of *cis*-**17** and *trans*-**17** (1:7.8) by treatment with 1 equiv of 1,5-diazabicyclo[5.4.0]undec-5-ene (DBU, THF reflux, 46 h).

In conclusion the results presented in this paper not only confirmed the *Z* structures of tertiary thioamide anions (>97% purity) and secondary thioamide dianions (~100% purity) but also offer a new methodology for the diastereoselective α allylation of thioamides, which might find a wide application in organic synthesis.

Experimental Section

Melting points were determined in capillary tubes with a Büchi apparatus and were not corrected. Unless otherwise specified, short-path (bulb-to-bulb) distillations were carried out in a Kugelrohr apparatus. Microanalyses were performed by the Microanalysis Center of Kyoto University. Analyses agreed with calculated values within ±0.3%. Infrared spectra were measured with a Hitachi Model EPI-G3 grating spectrophotometer. Proton magnetic resonance (^1H NMR) spectra were determined either at 60 MHz on a JEOL JNM-PMX60 instrument or at 100 MHz on a Varian HA-100 instrument with tetramethylsilane as an internal standard. ^{13}C NMR spectra were determined at 90 MHz on a JEOL FX-90Q instrument with $CDCl_3$ as an internal standard. Mass spectra were measured either on a Hitachi Model RMU 6C or on a JEOL D-300 instrument (high-resolution mass spectrophotometer).

Solvents and Reagents. Tetrahydrofuran (THF) was dried and distilled from benzophenone and sodium immediately prior to use under an argon atmosphere. Allylic alcohols, trimethylsilyl chloride, and 1,5-diazabicyclo[5.2.0]undec-5-ene were distilled over calcium hydride and kept under argon. *n*-Butyllithium (*n*-hexane solution) and 9-BBN were purchased from Aldrich Chemical Co. Cinnamyl bromide was used after recrystallization (*n*-hexane, mp 26–28 °C; 100% trans as determined by ^1H and ^{13}C NMR). *trans*-Crotyl alcohol, purchased from Aldrich Chemical Co., was used after distillation (over CaH_2). *cis*-Crotyl alcohol was prepared according to the literature procedure[15a] by a partial hydrogenation of 2-butyn-1-ol. Analysis by VPC (3-m PEG column, 80 °C, He carrier) indicated that the *trans*-crotyl alcohol was contaminated with 3.6% cis alcohol and that the *cis*-crotyl alcohol was contaminated with ca. 1% trans alcohol. *trans*-Crotyl bromide was prepared from crotyl alcohol by treatment with 1.2 equiv of phosphorous tribromide in dichloromethane at 0–5 °C (85% yield). Analysis by ^1H and ^{13}C NMR indicated that this material consisted of 70% *trans*-crotyl bromide, 10% cis isomer, and 20% α-methallyl bromide. *cis*- and *trans*-4-(trimethylsiloxy)-2-butenyl chlorides were prepared from the corresponding *cis*- and *trans*-4-hydroxy-2-butenyl chloride,[22] respectively (1.3 equiv of trimethylsilyl chloride in the presence of 1.4 equiv of triethylamine in ether at ambient temperature for 2 h).

***cis*-4-(Trimethylsiloxy)-2-butenyl chloride** (a mixture of 90.9% cis and 9.1% trans, as judged from VPC (PEG, 110 °C)): yield 92%; bp 86 °C (18 mmHg); IR (neat film) 2950 (m), 1650 (w), 1270 (s), 1020 cm^{-1} (s); ^1H NMR ($CDCl_3$) δ 0.13 (s, 9 H), 2.86–4.18 (m, 4 H), 5.66–5.93 (m, 2 H).

***trans*-4-(Trimethylsiloxy)-2-butenyl chloride** (a mixture of 90.6% trans and 9.4% cis): yield 96%; bp 88 °C (18 mmHg); IR (neat film) 2975 (m), 1675 (w), 1270 (s), 1115 (s), 970 cm^{-1} (s); ^1H NMR ($CDCl_3$) δ 0.13 (s, 9 H), 4.00–4.26 (m, 4 H), 5.80–6.10 (m, 2 H).

General Procedure for α-Allylation of Tertiary Thioamides. The reaction was carried out under argon, and all reagents were transfered via a syringe through a septum cap under an argon atmosphere. Into a solution of tertiary thioamide **6** in anhydrous THF was added *n*-butyllithium (1.1 equiv in *n*-hexane solution) at −78 °C, and the mixture was stirred for an additional hour at the same temperature. To this mixture was added a THF solution of the tosylate (1.1 equiv), which had been prepared in situ beforehand by a lithiation of the allylic alcohol with 1.0 equiv (relative to alcohol) of *n*-butyllithium, followed by addition of 1.0 equiv (relative to alcohol) of toluenesulfonyl chloride (at −78 °C, THF). After being stirred at −78 °C for 30 min, the reaction mixture was allowed to warm to an ambient temperature and then refluxed for 2 h. The mixture was poured into water and extracted twice with ethyl acetate. The combined extracts were dried over magnesium sulfate. Evaporation of the solvent left a faintly red or yellow oil, which was purified by means of a medium-pressure chromatography or by preparative thin-layer chromatography (silica gel, benzene–ethyl acetate). Physical, spectral and analytical data of the products listed in Table I are as follows.

***erythro*-*N*,*N*-Dimethyl-2,3-dimethylthiopent-4-enamide (*erythro*-7a)**: bp 150 °C (5 mmHg); IR (neat film) 3090 (w), 2960 (s), 2920 (m), 1510 (s), 1390 (s), 1275 (s), 1130 (m), 915 cm^{-1} (m); ^1H NMR ($CDCl_3$) δ 0.93 (d, *J* = 6.2 Hz, 3 H), 1.18 (d, *J* = 6.2 Hz, 3 H), 2.80 (m, 1 H), 2.90 (dq, *J* = 6.2, 9.8 Hz, 1 H), 3.37 (s, 3 H), 3.53 (s, 3 H), 5.1 (m, 2 H), 5.74 (ddd, *J* = 7.5, 9.7, 17.0 Hz, 1 H); ^{13}C NMR ($CDCl_3$) δ 18.9 (C_3-*Me*), 20.0 (C_2-*Me*), 41.2, 44.9 (NMe), 44.5 (C_3), 47.2 (C_2), 114.8 (C_5), 141.5 (C_4), 209.2 (C_1); mass spectrum *m*/*e* (relative intensity) 171 (M^+, 25), 156 (100), 116 (26), 88 (42), 84 (32). Anal. Calcd for $C_9H_{17}NS$: C, 63.10; H, 10.01; N, 8.18. Found: C, 63.19; H, 10.09; N, 8.41.

***threo*-*N*,*N*-Dimethyl-2,3-dimethylthiopent-4-enamide (*threo*-7a)**: bp 150 °C (5 mmHg); IR (neat film) 3090 (w), 2970 (s), 2930 (s), 1510 (s), 1390 (s), 1275 (s), 1155 (s), 915 cm^{-1} (m); ^1H NMR ($CDCl_3$) δ 1.09 (d, *J* = 6.7 Hz, 3 H), 1.24 (d, *J* = 6.4 Hz, 3 H), 2.8 (m, 2 H), 3.33 (s, 3 H), 3.48 (s, 3 H), 5.0 (m, 2 H), 5.77 (ddd, *J* = 7.0, 10.3, 17.2 Hz, 1 H); ^{13}C NMR ($CDCl_3$) δ 16.0 (C_3-*Me*, 18.7 (C_2-*Me*), 41.4, 44.5 (NMe), 43.0 (C_3), 47.5 (C_2), 113.7 (C_5), 141.9 (C_4), 209.0 (C_1); mass spectrum, *m*/*e* (relative intensity) 171 (M^+, 32), 156 (100), 116 (31), 88 (46), 84 (35). Anal. Calcd for $C_9H_{17}NS$: C, 63.10; H, 10.01; N, 8.18. Found: C, 63.21; H, 10.19; N, 8.00.

***erythro*-*N*,*N*-Dimethyl-2-methyl-3-phenylthiopent-4-enamide (*erythro*-7b)**: mp 125–126 °C (*n*-hexane–ethanol); IR (KBr) 2950 (m), 1490 (s), 1380 (m), 1265 (s), 1140 (m), 1110 (m), 980 (m), 935 (s), 760 (s), 700 cm^{-1} (s); ^1H NMR (CCl_4) δ 1.34 (d, *J* = 7.0 Hz, 3 H), 3.01 (s, 3 H), 3.27 (s, 3 H), 3.60 (dq, *J* = 10.4, 7.0 Hz, 1 H), 3.85 (dd, *J* = 10.4, 8.8 Hz, 1 H), 5.0–5.5 (m, 2 H), 5.9–6.4 (m, 1 H), 7.28 (br s, 5 H); mass spectrum, *m*/*e* (relative intensity) 233 (M^+, 11), 218 (100), 117 (17), 116 (46), 115 (36), 91 (24), 88 (37). Anal. Calcd for $C_{14}H_{19}NS$: C, 72.04; H, 8.20; N, 6.00. Found: C, 71.91; H, 8.23; N, 5.86.

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(22) Colonge, J.; Poiloue, G. *Bull. Soc. Chim. Fr.* **1955**, 953.

***erythro*-*N*,*N*-Dimethyl-2-methyl-3-[(trimethylsiloxy)methyl]thiopent-4-enamide (*erythro*-7c)**: bp 110 °C (2 mmHg); IR (neat film) 2950 (s), 1640 (w), 1505 (s), 1250 (s), 1095 (s), 990 (s), 910 cm^{-1} (s); ^1H NMR ($CDCl_3$) δ 0.10 (s, 9 H), 1.27 (d, J = 7.0 Hz, 3 H), 2.5–2.8 (m, 1 H), 3.18 (s, 3 H), 3.38 (s, 3 H), 3.39 (dq, J = 9.0, 7.0 Hz, 1 H), 3.64 (dd, J = 10.4, 5.6 Hz, 1 H), 3.72 (dd, J = 10.4, 4.2 Hz, 1 H), 4.9–5.2 (m, 2 H), 5.86 (ddd, J = 18.0, 10.0, 9.8 Hz, 1 H); mass spectrum, m/e (relative intensity) 259 (M^+, 51), 244 (49), 171 (16), 154 (76), 143 (13), 117 (100), 84 (70). Anal. Calcd for $C_{12}H_{25}NOSSi$: C, 55.54; H, 9.71; N, 5.40. Found: C, 55.44; H, 9.93; N, 5.35.

***threo*-*N*,*N*-Dimethyl-2-methyl-3-[(trimethylsiloxy)methyl]thiopent-4-enamide (*threo*-7c)**: bp 110 °C (2 mmHg); IR (neat film) 2980 (s), 1640 (w), 1505 (s), 1390 (s), 1250 (s), 1100 (s), 990 (s), 905 cm^{-1} (s); ^1H NMR ($CDCl_3$) δ 0.05 (s, 9 H), 1.16 (d, J = 6.1 Hz, 3 H), 2.58–2.90 (m, 1 H), 3.24 (dq, J = 6.1, 3.0 Hz, 1 H), 3.35 (s, 3 H), 3.50 (s, 3 H), 3.44–3.74 (m, 1 H), 3.70 (dd, J = 10.0, 6.0 Hz, 1 H), 5.02–5.28 (m, 2 H), 5.62 (ddd, J = 17.0, 9.0, 9.0 Hz, 1 H); mass spectrum m/e (relative intensity) 259 (M^+, 68), 244 (67), 171 (16), 154 (76), 143 (73), 117 (100), 84 (70). Anal. Calcd for $C_{12}H_{25}NOSSi$: C, 55.54; H, 9.71; N, 5.40. Found: C, 55.35; H, 9.82; N, 5.50.

***erythro*-*N*,*N*-Diisopropyl-2,3-dimethylthiopent-4-enamide (*erythro*-7d)**: bp 145 °C (1.0 mmHg); IR (neat film) 3060 (w), 2940 (s), 2910 (s), 2850 (w), 1475 (s), 1445 (m), 1365 (s), 1105 (m), 910 cm^{-1} (m); ^1H NMR ($CDCl_3$) δ 0.89–1.63 (m, 18 H), 2.59–3.09 (m, 2 H), 3.73–4.47 (m, 1 H), 4.85–5.25 (m, 2 H), 5.44–6.46 (m, 2 H); mass spectrum m/e (relative intensity) 227 (M^+, 8), 212 (37), 184 (100), 102 (35), 100 (28), 96 (68). Anal. Calcd for $C_{13}H_{25}NS$: C, 68.66; H, 11.08; N, 6.16. Found: C, 68.77; H, 10.97; N, 6.25.

***threo*-*N*,*N*-Diisopropyl-2,3-dimethylthiopent-4-enamide (*threo*-7d)**: bp 145 °C (1.0 mmHg); IR (neat film) 3060 (w), 2950 (s), 2910 (m), 2850 (w), 1475 (s), 1445 (m), 1365 (s), 1110 (m), 910 cm^{-1} (m); ^1H NMR ($CDCl_3$) δ 1.06–1.53 (m, 18 H), 2.63–3.16 (m, 2 H), 3.81–4.39 (m, 1 H), 4.78–5.29 (m, 2 H), 5.42–6.58 (m, 2 H); mass spectrum, m/e (relative intensity) 227 (M^+, 10), 212 (37), 184 (100), 102 (37), 100 (30), 96 (68). Anal. Calcd for $C_{13}H_{25}NS$: C, 68.66; H, 11.08; N, 6.16. Found: C, 68.77; H, 10.90; N, 6.25.

***N*,*N*-Dimethyl-2-isopropyl-3-methylthiopent-4-enamide (a mixture of *erythro*- and *threo*-7e, 1:1)**: bp 125 °C (0.3 mmHg); IR (neat film) 3000 (s), 1640 (w), 1500 (s), 1390 (s), 1000 (m), 910 cm^{-1} (m); ^1H NMR ($CDCl_3$) δ 0.86–1.23 (m, 9 H), 2.0–2.6 (m, 1 H), 2.7–3.1 (m, 2 H), 3.43 (s, 3 H), 3.56 (s, 3 H), 4.93–5.43 (m, 2 H), 5.48–6.76 (m, 1 H); mass spectrum m/e (relative intensity) 199 (M^+, 14), 156 (100), 143 (88), 88 (68). Anal. Calcd for $C_{11}H_{21}NS$: C, 66.27; H, 10.62; N, 7.03. Found: C, 66.54; H, 10.80; N, 6.91.

***erythro*-*N*,*N*-Dimethyl-2-phenyl-3-methylthiopent-4-enamide (*erythro*-7f)**: mp 87.0–88.0 °C (from *n*-hexane–ethanol); IR (KBr) 3060 (w), 2950 (m), 2910 (m), 2850 (w), 1510 (s), 1385 (s), 1275 (s), 918 (s), 712 (s), 700 cm^{-1} (s); ^1H NMR (CCl_4) δ 1.09 (d, J = 6.0 Hz, 3 H), 3.35 (s, 3 H), 3.39 (s, 3 H), 3.16–3.93 (m, 22 H), 4.55–4.96 (m, 2 H), 5.16–5.75 (m, 1 H), 7.06–7.53 (m, 5 H); ^{13}C NMR ($CDCl_3$) δ 19.3 (C_3-*Me*), 41.4, 45.2 (NMe), 44.4 (C_3), 60.3 (C_2), 114.3 (C_5), 141.5 (C_4), 127.0, 128.1, 129.2, 138.8 (phenyl), 204.5 (C_1); mass spectrum, m/e (relative intensity) 233 (M^+, 13), 218 (83), 178 (95), 156 (36), 146 (36), 144 (37), 135 (33), 134 (46), 128 (33), 91 (50), 88 (100). Anal. Calcd for $C_{14}H_{19}NS$: C, 72.04; H, 8.20; N, 6.00. Found: C, 71.77; H, 8.27; N, 5.99.

***threo*-*N*,*N*-Dimethyl-2-phenyl-3-methylthiopent-4-enamide (*threo*-7f)**: bp 128–132 °C (0.06 mmHg); IR (neat film) 3060 (m), 2950 (s), 2920 (s), 2860 (m), 1500 (s), 1380 (s), 1275 (s), 1140 (s), 915 (m), 775 (m), 700 cm^{-1} (s); ^1H NMR (CCl_4) δ 0.74 (d, J = 6.0 Hz, 3 H), 3.35 (s, 3 H), 3.39 (s, 3 H), 3.2–3.9 (m, 2 H), 4.8–6.3 (m, 3 H), 7.1–7.7 (m, 5 H); ^{13}C NMR ($CDCl_3$) δ 17.4 (C_3-*Me*), 41.4, 45.0 (NMe), 42.7 (C_3), 60.2 (C_2), 113.9 (C_5), 142.7 (C_4), 127.0, 128.2, 129.1, 138.5 (phenyl), 204.4 (C_1); mass spectrum, m/e (relative intensity) 233 (M^+, 19), 218 (37), 178 (45), 156 (16), 146 (16), 144 (17), 135 (16), 134 (24), 128 (16), 91 (52), 88 (100). Anal. Calcd for $C_{14}H_{19}NS$: C, 72.04; H, 8.20; N, 6.00. Found: C, 72.17; H, 8.35; N, 5.97.

***erythro*-*N*,*N*-Dimethyl-2,3-diphenylthiopent-4-enamide (*erythro*-7g)**: mp 166–168 °C (n-hexane–ethanol); IR (KBr) 3020 (w), 2920 (w), 1600 (w), 1490 (s), 1380 (m), 1270 (s), 1140 (m), 1090 (m), 990 (m), 920 (s), 780 (m), 760 (m), 720 (s), 700 cm^{-1} (s); ^1H NMR ($CDCl_3$) δ 3.22 (s, 3 H); 3.30 (s, 3 H), 4.54–4.96 (m, 4 H), 5.46–6.12 (m, 1 H), 7.09–7.83 (m, 10 H); mass spectrum, m/e (relative intensity) 295 (M^+, 19), 280 (7), 218 (35), 204 (11), 178 (100). Anal. Calcd for $C_{19}H_{21}NS$: C, 77.25; H, 7.17; N, 4.74. Found: C, 77.19; H, 7.10; N, 4.80.

***threo*-*N*-Methyl-3-(1-methyl-2-propenyl)pyrrolidine-2-thione (*threo*-7h, a mixture of 62% *threo*-7h and 38% *erythro*-7h)**: bp 110–115 °C (0.25 mmHg); IR (neat film) 3090 (w), 2960 (m), 2870 (m), 1520 (s), 1305 (s), 1135 (m), 915 cm^{-1} (m); ^1H NMR (CCl_4) δ 0.88 (d, J = 6.6 Hz, 1.86 H), 1.11 (d, J = 6.6 Hz, 1.14 H), 1.6–2.4 (m, 2 H), 2.8–3.5 (m, 2 H), 3.33 (s, 3 H), 3.5–3.9 (m, 2 H), 4.9–6.3 (m, 3 H); mass spectrum, m/e (relative intensity) 169 (M^+, 35), 168 (13), 154 (24), 136 (100), 115 (52), 114 (69), 82 (59). Anal. Calcd for $C_9H_{15}NS$: C, 63.85; H, 8.93; N, 8.27. Found: C, 64.01; H, 9.18; N, 8.51.

***threo*-*N*-Methyl-3-(1-phenyl-2-propenyl)pyrrolidine-2-thione (*threo*-7i)**. This sample was prepared according to a *S*-alkyl onion method:[6d] bp 140 °C (0.15 mmHg); IR (neat film) 2950 (m), 1640 (w), 1600 (w), 1530 (s), 1450 (s), 1000 (w), 920 cm^{-1} (m); ^1H NMR ($CDCl_3$) δ 1.89–2.59 (m, 3 H), 3.02 (s, 3 H), 3.1–3.6 (m, 2 H), 4.43 (m, 1 H, collapsing to a doublet, J = 2.9 Hz, upon irradn. at 6.20), 5.08–5.30 (m, 2 H), 6.20 (ddd, J = 16.6, 10.7, 8.5 Hz, 1 H) 7.25 (m, 5 H); ^{13}C NMR ($CDCl_3$) δ 21.37 (C_3), 35.02 (NMe), 49.98 (C_1'), 55.49 (C_4), 57.94 (C_2), 115.11 (C_3'), 138.75 (C_2'), 126.84, 127.68, 128.52, 139.11 (phenyl), 202.74 (C_1); mass spectrum, m/e (relative intensity) 231 (M^+, 76), 198 (100), 117 (72). Anal. Calcd for $C_{14}H_{17}NS$: C, 72.68; H, 7.41; N, 6.05. Found: C, 72.89; H, 7.46; N, 5.80.

***threo*-*N*-Methyl-α-(1-methyl-2-propenyl)thio-δ-valerolactam (*threo*-7j)**. The stereochemically pure sample was prepared according to the *S*-alkyl onium salt methods:[6d] bp 128–135 °C (0.2 mmHg); IR (neat film) 3075 (w), 2940 (s), 2860 (m), 1515 (s), 1340 (s), 1235 (s), 905 (m); ^1H NMR (CCl_4) δ 0.85 (d, J = 6.8 Hz, 3 H; *erythro*-**7g** 1.13 (d, J = 6.7 Hz, 3 H)), 1.29–2.16 (m, 4 H), 2.49–2.91 (m, 1 H), 3.44 (s, 3 H), 3.31–3.97 (m, 3 H), 4.83–5.24 (m, 2 H), 5.63–6.25 (m, 1 H); mass spectrum, m/e (relative intensity) 183 (M^+, 42), 182 (26), 168 (100), 149 (99), 104 (66). Anal. Calcd for $C_{10}H_{17}NS$: C, 65.52; H, 9.35; N, 7.64. Found: C, 65.46; H, 9.52; N, 7.70.

General Procedure for α Allylation of Secondary Thioamides. Into a solution of secondary thioamide **10** in anhydrous THF was added *n*-butyllithium (2.2 equiv in *n*-hexane solution) at 0 °C. After being stirred at 0 °C for 1 h, the mixture was cooled to −78 °C, and then 1.1 equiv of trimethylsilyl chloride was added. The mixture was stirred at −78 °C for 30 min and then allowed to warm to 0 °C. After being stirred at 0 °C for 1 h, the mixture was cooled again to −78 °C, and then a THF solution of tosylate (1.1 equiv), prepared in situ beforehand by a lithiation of allylic alcohol with 1.0 equiv (relative to alcohol) of *n*-butyllithium followed by addition of 1.0 equiv (relative to alcohol) of toluenesulfonyl chloride (at −78 °C, THF), was added into this mixture. The mixture, after being stirred for 30 min at −78 °C, was allowed to warm to ambient temperature and then subjected to the thio-Claisen rearrangement conditions indicated in Table II. After an extractive workup, the product was purified by means of a medium-pressure chromatography or by preparative thin-layer chromatography (silica gel, benzene–ethyl acetate). Physical, spectral, and analytical data of the products listed in Table II are as follows.

***erythro*-*N*-Phenyl-2,3-dimethylthiopent-4-enamide (*erythro*-11a)**: mp 66.5–67.0 °C (from *n*-hexane); IR (KBr) 3200 (s), 2900 (s), 1640 (w), 1600 (m), 1500 (s), 1410 (s), 990 (m), 910 cm^{-1} (s); ^1H NMR (CCl_4) δ 0.99 (d, J = 5.8 Hz, 3 H), 1.10 (d, J = 5.6 Hz, 3 H), 2.10–2.73 (m, 2 H), 4.73–5.23 (m, 2 H), 5.33–6.06 (m, 1 H), 7.3 (m, 5 H), 9.4 (br s, 1 H); mass spectrum, m/e (relative intensity) 219 (M^+, 37), 204 (100). Anal. Calcd for $C_{13}H_{17}NS$: C, 71.18; H, 7.81; N, 6.39. Found: C, 71.18; H, 7.93; N, 6.42.

***threo*-*N*-Phenyl-2,3-dimethylthiopent-4-enamide (*threo*-11a)**: mp 95.0–95.5 °C (from *n*-hexane); IR (KBr) 3110 (s), 3000 (s), 1640 (w), 1590 (w), 1510 (s), 1410 (s), 990 (m), 910 cm^{-1} (m); ^1H NMR (CCl_4) δ 1.00 (d, J = 6.0 Hz, 3 H), 1.13 (d, J = 5.8 Hz, 3 H), 2.16–2.83 (m, 2 H), 4.73–5.20 (m, 2 H), 5.43–6.06 (m, 1 H), 7.03–7.70 (m, 5 H), 9.2 (br s, 1 H); mass spectrum, m/e (relative intensity) 219 (M^+, 43), 204 (100). Anal. Calcd for $C_{13}H_{17}NS$: C, 71.18; H, 7.81; N, 6.39. Found: C, 71.29; H, 7.89; N, 6.17.

***erythro*-*N*-Phenyl-2-methyl-3-phenylthiopent-4-enamide (*erythro*-11b)**: mp 114.5–116.0 °C (from *n*-hexane); IR (KBr)

3210 (s), 3000 (s), 1640 (w), 1600 (s), 1540 (s), 1410 (s), 990 (s), 760 cm^{-1} (s); ^1H NMR ($CDCl_3$) δ 1.45 (d, J = 6.6 Hz, 3 H), 2.70–3.30 (m, 1 H), 3.43–4.00 (m, 1 H), 5.00–5.43 (m, 2 H), 6.77–7.53 (m, 1 H), 6.91–7.58 (m, 10 H), 8.30 (br s, 1 H); mass spectrum, m/e (relative intensity) 281 (M^+, 21), 266 (100), 117 (60). Anal. Calcd for $C_{18}H_{19}NS$: C, 76.82; H, 6.81; N, 4.98. Found: C, 76.97; H, 6.88; N, 4.87.

***erythro*-*N*-Phenyl-2-methyl-3-[(trimethylsiloxy)methyl]thiopent-4-enamide (*erythro*-11c)**: bp 140 °C (2 mmHg); IR (neat film) 2995 (s), 1640 (w), 1600 (m), 1500 (s), 1405 (s), 1250 (s), 1100 (s), 990 (m), 910 (m), 840 cm^{-1} (s); ^1H NMR ($CDCl_3$) δ 0.10 (s, 9 H), 1.34 (d, J = 7.0 Hz, 3 H), 2.30–3.58 (m, 2 H), 3.58–4.00 (m, 2 H), 5.00–5.45 (m, 2 H), 5.56–6.26 (m, 1 H), 7.20–7.93 (m, 5 H), 9.5 (br s, 1 H); mass spectrum, m/e (relative intensity) 308 (M^+, 7), 292 (20), 165 (100). Anal. Calcd for $C_{16}H_{25}NOSSi$; C, 62.49; H, 8.19; N, 4.56. Found: C, 62.51; H, 8.19; N, 4.56.

***threo*-*N*-Phenyl-2-methyl-3-[(trimethylsiloxy)methyl]thiopent-4-enamide (*threo*-11c)**: bp 140 °C (2 mmHg); IR (neat film) 2995 (s), 1640 (w), 1600 (m), 1500 (s), 1410 (s), 1250 (s), 1100 (s), 990 (s), 940 (s), 840 cm^{-1} (s); ^1H NMR ($CDCl_3$) δ 0.10 (s, 9 H), 1.27 (d, J = 7.0 Hz, 3 H), 2.20–3.23 (m, 2 H), 3.40–3.97 (m, 2 H), 4.97–5.25 (m, 2 H), 5.53–6.23 (m, 1 H), 7.17–7.93 (m, 5 H), 9.5 (br s, 1 H); mass spectrum m/e (relative intensity) 308 (M^+, 3), 292 (15), 165 (100). Anal. Calcd for $C_{16}H_{25}NOSSi$: C, 62.49; H, 8.19; N, 4.56. Found: C, 62.33; H, 8.07; N, 4.59.

***erythro*-*N*-Phenyl-2-phenyl-3-methylthiopent-4-enamide (*erythro*-11d)**: mp 97–98 °C (from *n*-hexane–benzene); IR (KBr) 3200 (s), 2900 (s), 1640 (w), 1600 (m), 1500 (s), 1400 (s), 990 (m), 910 cm^{-1} (s); ^1H NMR ($CDCl_3$) δ 1.20 (d, J = 6.0 Hz, 3 H), 3.30–3.50 (m, 1 H), 3.73 (d, J = 9.5 Hz, 1 H), 4.80–5.26 (m, 2 H), 5.66 (ddd, J = 16.9, 9.7, 6.0 Hz, 1 H), 7.13–7.83 (m, 10 H), 8.8 (br s, 1 H); ^{13}C NMR ($CDCl_3$) δ 18.7 (Me), 41.6 (C_3), 69.1 (C_2) 115.1 (C_5), 141.2 (C_4), 204.6 (C_1); mass spectrum, m/e (relative intensity) 281 (M^+, 46), 266 (100). Anal. Calcd for $C_{18}H_{19}NS$: C, 76.82; H, 6.81; N, 4.98. Found: C, 76.68; H, 6.74; N, 4.86.

***threo*-*N*-Phenyl-2-phenyl-3-methylthiopent-4-enamide (*threo*-11d)**: mp 91–92 °C (benzene–hexane); IR (KBr) 3200 (m), 1640 (w), 1600 (m), 1500 (s), 1400 (s), 990 (w), 910 cm^{-1} (m); ^1H NMR ($CDCl_3$) δ 0.92 (d, J = 6.6 Hz, 3 H), 3.34 (m, 1 H), 3.73 (d, J = 10.3 Hz, 1 H), 5.0–5.4 (m, 2 H), 5.96 (ddd, J = 17.1, 10.0, 7.1 Hz, 1 H), 7.4 (m, 10 H), 8.8 (br s, 1 H); ^{13}C NMR ($CDCl_3$) δ 17.8 (Me), 41.6 (C_3), 69.0 (C_2), 114.9 (C_5), 141.2 (C_4), 204.5 (C_1); mass spectrum, m/e (relative intensity) 281 (M^+, 70), 266 (100). Anal. Calcd for $C_{18}H_{19}NS$: C, 76.82; H, 6.81; N, 4.98. Found: C, 76.61; H, 6.95; N, 5.07.

***erythro*-*N*-Phenyl-2,3-diphenylthiopent-4-enamide (*erythro*-11e)**: mp 168–170 °C (CH_2Cl_2–hexane); IR (KBr) 3302 (s), 2905 (w), 1640 (w), 1600 (m), 1500 (s), 1410 (s), 990 (w), 910 (m), 750 cm^{-1} (s); ^1H NMR ($CDCl_3$) δ 4.28 (d, J = 10.7 Hz, 1 H), 4.53 (dd, J = 10.7, 6.6 Hz, 1 H), 4.82–5.32 (m, 2 H), 5.75–6.21 (m, 1 H), 7.06–7.80 (m, 15 H), 8.50 (br s, 1 H); ^{13}C NMR ($CDCl_3$) δ 54.3 (C_3), 68.1 (C_2), 117.0 (C_5), 138.7 (C_4), 203.9 (C_1); mass spectrum, m/e (relative intensity) 343 (M^+, 100), 266 (44), 226 (98); calcd for $C_{23}H_{21}NS$ m/e 343.1395, found m/e 343.1413.

α Allylation of *N*,*N*-Dimethylthiopropionamide with *trans*-Crotyl Bromide (under Brandsma's Conditions). Into a solution of $NaNH_2$ (7.2 mmol, prepared from 165 mg of Na and 5 mg of $Fe(NO_3)_3$) in liquid ammonia (15 mL) was added at −78 °C a solution of *N*,*N*-dimethylthiopropionamide (6.0 mmol in 3 mL of THF) in one portion, and the mixture was stirred for 20 min. *trans*-Crotyl bromide (9 mmol in 2 mL of THF) was added, and the mixture was stirred at −78 °C for 5 min and at an ambient temperature overnight and then poured into ether. The organic layer was washed with aqueous NH_4Cl and then with aqueous NaCl and dried over $MgSO_4$. Evaporation of solvents and purification of the residue by column chromatography (silica gel, hexane–benzene) provided a mixture of *erythro*- and *threo*-**7a** (73:27, ^1H NMR and HPLC) in 60% isolated yield based on 60% conversion.

***N*,*N*-Dimethyl-2,3-dimethyl-5-hydroxythiopentamide (15).** Into a solution of *N*,*N*-dimethyl-2,3-dimethylthiopent-4-enamide (**7a**; 2.06 g, 12 mmol) in 12 mL of anhydrous THF was added 9-BBN (36 mL, 0.5 M THF solution) at ambient temperature, and this mixture was stirred overnight. Sodium hydroxide (3 N, 6.6 mL) and then hydrogen peroxide (30%, 9 mL) were added carefully with ice-cooling, maintaining the reaction temperature under 7 °C. The reaction mixture was stirred at an ambient temperature for an additional 3 h and then poured into water. Extraction with ether (3 × 50 mL), drying over $MgSO_4$, and evaporation of the solvent provided a viscous oil, which was purified by column chromatography (silica gel, *n*-hexane–ethyl acetate). ***erythro*-15**: yield 55%; bp 165–170 °C (0.28 mmHg); IR (neat film) 3400 (s), 2950 (s), 2860 (m), 1510 (s), 1390 (m), 1275 (s), 1145 (m), 1050 cm^{-1} (s); ^1H NMR ($CDCl_3$) δ 0.88 (d, J = 6.2 Hz, 3 H), 1.23 (d, J = 6.4 Hz, 3 H), 1.3–2.4 (m, 3 H), 1.77 (s, 1 H), 2.88 (dq, J = 6.4, 8.6 Hz, 1 H), 3.37 (s, 3 H), 3.54 (s, 3 H), 3.71 (t, J = 7.6 Hz, 2 H); ^{13}C NMR ($CDCl_3$) δ 18.2 (C_3-*Me*), 18.5 (C_2-*Me*), 35.5 (C_4), 36.0 (C_3), 41.3, 44.6 (NMe), 47.8 (C_2), 60.8 (C_5), 209.9 (C_1); mass spectrum, m/e (relative intensity) 171 (28), 156 (64), 128 (100), 104 (63). Anal. Calcd for $C_9H_{19}NOS$: C, 57.10; H, 10.12; N, 7.40; O, 8.45. Found: C, 57.03; H, 10.35; N, 7.30; O, 8.75. ***threo*-15**: yield 74%; bp 160–165 °C (0.25 mmHg); IR (neat film) 3420 (s), 1520 (s), 1395 (m), 1280 (s), 1155 (m), 1045 (m), 1000 cm^{-1} (w); ^1H NMR ($CDCl_3$) δ 1.01 (d, J = 6.6 Hz, 3 H), 1.20 (d, J = 6.6 Hz, 3 H), 1.3–2.4 (m, 3 H), 1.90 (s, 1 H), 2.86 (dq, J = 6.6, 6.0 Hz, 1 H), 3.40 (s, 3 H), 3.56 (s, 3 H), 3.66 (dd, J = 7.3, 6.1 Hz, 2 H); ^{13}C NMR ($CDCl_3$) δ 16.5 (C_3-*Me*), 18.6 (C_2-*Me*), 35.4 (C_3), 38.6 (C_4), 41.2, 44.8 (NMe), 48.1 (C_2), 60.8 (C_5), 210.1 (C_1); mass spectrum, m/e (relative intensity) 171 (12), 156 (100), 128 (53), 88 (64), 84 (74). Anal. Calcd for $C_9H_{19}NOS$: C, 57.10; H, 10.12; N, 7.40; O, 8.45. Found: C, 57.30; H, 10.23; N, 7.30; O, 8.74.

1,2-Dimethyl-δ-valerolactone (16). *N*,*N*-Dimethyl-2,3-dimethyl-5-hydroxythiopentamide (**15**; 189 mg, 1 mmol) was treated with methyl iodide (622 μL, 10 equiv) and 2 N HCl (1 mL, 2 equiv) in THF (5 mL) at room temperature overnight. The mixture was extracted with ether (2 × 30 mL), and the ether extracts were washed with aqueous Na_2SO_3 and then with aqueous $NaHCO_3$. During this lactonization an epimerization took place slightly: a mixture of *cis*-**16** (91%) and *trans*-**16** (9%) from a mixture of *erythro*-**15** (96%) and *threo*-**15** (4%); a mixture of *trans*-**16** (87%) and *cis*-**16** (18%) from a mixture of *threo*-**15** (84%) and *erythro*-**15** (16%). ***cis*-16**: yield 57%, bp 88–92 °C (0.25 mmHg); IR (neat film) 2990 (m), 1735 (s), 1460 (m), 1395 (m), 1260 (m), 1180 (m), 1100 cm^{-1} (m); ^1H NMR (CCl_4) δ 0.96 (d, J = 6.8 Hz, 3 H), 1.13 (d, J = 7.2 Hz, 3 H), 1.47–1.83 (m, 1 H), 1.89–2.44 (m, 2 H), 2.49–3.78 (m, 1 H), 4.16–4.32 (m, 2 H); a multiplet at δ 2.49–3.78 collapsed to a doublet (J = 6.0 Hz) by irradiation at δ 1.13; ^{13}C NMR ($CDCl_3$) δ 12.5 (C_2-*Me*), 16.6 (C_3-*Me*), 29.6 (C_4), 38.9 (C_2), 66.4 (C_5), 175.0 (C_1); mass spectrum, m/e (relative intensity) 128 (M^+, 10), 113 (10), 72 (100); calcd for $C_7H_{12}O_2$ m/e 128.0837, found m/e 128.0840. ***trans*-16**: yield 32%; bp 80–85 °C (0.6 mmHg); IR (neat film) 2990 (m), 1735 (s), 1460 (m), 1400 (m), 1260 (m), 1190 (m), 1105 cm^{-1}; ^1H NMR (CCl_4) δ 1.04–1.32 (m, 6 H), 1.44–2.39 (m, 6 H), 4.12–4.40 (m, 2 H); by doping with $Eu(fod)_3$, the overlapped absorptions corresponding to two methyl groups and the C_2 proton were separated and well resolved to give two doublets (J = 6.6, 6.0 Hz) and a doublet of quartets (J = 6.6, 9.0 Hz); ^{13}C NMR ($CDCl_3$) δ 14.5 (C_2-*Me*), 20.4 (C_3-*Me*), 30.9 (C_3), 33.0 (C_4), 42.3 (C_2), 66.9 (C_5), 174.5 (C_1); mass spectrum, m/e (relative intensity) 128 (M^+, 11), 113 (8), 72 (100). Anal. Calcd for $C_7H_{12}O_2$: 128.0837. Found: 128.0856.

2-Methyl-3-vinyl-γ-butyrolactone (17). A mixture of *N*,*N*-dimethyl-2-methyl-3-[(trimethylsiloxy)methyl]thiopent-4-enamide (**7c**; 1 mmol), methyl iodide (622 μL, 10 mmol), and 2 N HCl (1 mL) in 5 mL of THF was stirred overnight at room temperature. This mixture was extracted with ether (2 × 30 mL). The combined ether extracts were washed with aqueous Na_2SO_3 and then with aqueous $NaHCO_3$. The solvent was removed by a careful distillation through a Vigreux column, and the residue was distilled under reduced pressure to provide **17**. According to the same procedure, *N*-phenyl-2-methyl-3-[(trimethylsiloxy)methyl]thiopent-4-enamide (**11c**) was converted to **17**. During this transformation the stereochemical integrity at C_2 remained intact. ***cis*-17**: yield 83% (from *erythro*-**7c**), 53% (from *erythro*-**11c**); bp 100 °C (12 mmHg); IR (neat film) 3000 (m), 1780 (s), 1645 (w), 1010 (s), 920 cm^{-1} (s); ^1H NMR ($CDCl_3$) δ 1.17 (d, J = 7.6 Hz, 3 H), 2.74 (dq, J = 8.8, 7.6 Hz, 1 H), 3.00–3.30 (m, 1 H), 4.19 (dd, J = 9.0, 6.0 Hz, 1 H), 4.41 (dd, J = 9.0, 7.0 Hz, 1 H), 4.98–5.34 (m, 2 H), 4.58–5.96 (m, 1 H); ^{13}C NMR ($CDCl_3$) δ 10.8 (C_1-*Me*), 38.1 (C_3), 44.1 (C_2), 70.7 (C_4), 118.5 (CH_2=), 133.8 (CH=), 179.2

(C_1); mass spectrum, m/e (relative intensity) 126 (M^+, 17), 96 (45), 68 (100); calcd for $C_7H_{10}O_2$ m/e 126.0681, found m/e 126.0687. ***trans*-17**: yield 65% (from *threo*-**7c**), 49% (from **11c**); bp 103 °C (12 mmHg); IR (neat film) 3000 (m), 1780 (s), 1645 (w), 1010 (s), 920 cm^{-1} (s); ^1H NMR ($CDCl_3$) δ 1.24 (d, J = 7.6 Hz, 3 H), 2.36 (dq, J = 12.0, 7.6 Hz, 1 H), 2.62–2.90 (m, 1 H), 3.93 (dd, J = 9.0, 9.0 Hz, 1 H), 4.40 (dd, J = 9.0, 8.0 Hz, 1 H), 5.12–5.36 (m, 2 H), 5.66 (ddd, J = 18.0, 9.0, 8.0 Hz, 1 H); ^{13}C NMR ($CDCl_3$) δ 12.8 (C_2-*Me*), 40.0 (C_3), 48.7 (C_2), 69.8 (C_4), 118.6 (CH_2=), 134.7 (CH=), 178.1 (C_1); mass spectrum, m/e (relative intensity) 126 (M^+, 4), 96 (9), 68 (100); calcd for $C_7H_{10}O_2$ m/e 126.0681, found m/e 126.0687.

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Registry No. **6a**, 5309-94-4; **6b**, 78904-41-3; **6c**, 67797-33-5; **6d**, 17709-95-4; **6e**, 10441-57-3; **6f**, 13070-07-0; *erythro*-**7a**, 76454-96-1; *threo*-**7a**, 76454-95-0; *erythro*-**7b**, 85892-04-2; *threo*-**7b**, 85892-05-3; *erythro*-**7c**, 86943-07-9; *threo*-**7c**, 86943-08-0; *erythro*-**7d**, 86943-09-1; *threo*-**7d**, 86943-10-4; *erythro*-**7e**, 85892-08-6; *threo*-**7e**, 85892-09-7; *erythro*-**7f**, 85892-15-5; *threo*-**7f**, 85892-14-4; *erythro*-**7g**, 86943-11-5; *threo*-**7g**, 86943-12-6; *erythro*-**7h**, 86943-13-7; *threo*-**7h**, 86943-14-8; *erythro*-**7i**, 86943-15-9; *threo*-**7i**, 86943-16-0; *erythro*-**7j**, 85892-17-7; *threo*-**7j**, 85892-18-8; **10a**, 2955-69-3; **10b**, 6636-01-7; *erythro*-**11a**, 82080-82-8; *threo*-**11a**, 82080-83-9; *erythro*-**11b**, 86943-17-1; *threo*-**11b**, 86943-18-2; *erythro*-**11c**, 86943-19-3; *threo*-**11c**, 86943-20-6; *erythro*-**11d**, 86943-21-7; *threo*-**11d**, 86943-22-8; *erythro*-**11e**, 86943-23-9; *threo*-**11e**, 86943-24-0; *erythro*-**15**, 86943-25-1; *threo*-**15**, 86943-26-2; *cis*-**16**, 86943-27-3; *trans*-**16**, 86943-28-4; *cis*-**17**, 86943-29-5; *trans*-**17**, 78657-18-8; *trans*-crotyl alcohol, 504-61-0; *cis*-crotyl alcohol, 4088-60-2; *trans*-4-[(trimethylsilyl)oxy]-2-butenyl chloride, 86943-30-8; *cis*-4-[(trimethylsilyl)oxy]-2-butenyl chloride, 86943-31-9; *trans*-crotyl bromide, 29576-14-5; α-methallyl bromide, 22037-73-6; *trans*-cinnamyl bromide, 26146-77-0; *trans*-cinnamyl alcohol, 4407-36-7; *N*-methyl-3-(*trans*-cinnamyl)pyrolidine-2-thione, 86943-32-0.

[1 + 4] Cycloaddition of Isocyanides with 1-Aryl-2-nitro-1-propenes, Methyl 2-Nitro-3-arylpropenoates, and Methyl 2-Nitro-2,4-pentadienoates. Synthesis of 1-Hydroxyindoles and 1-Hydroxypyrroles

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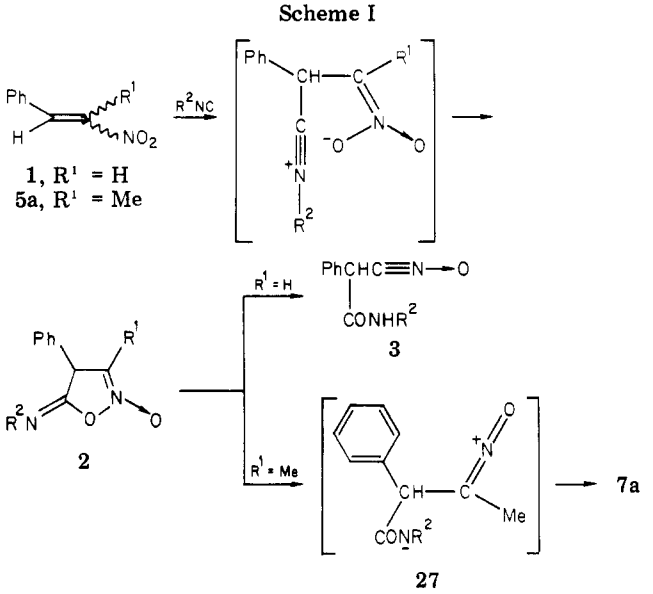
The [1 + 4] cycloadditions of isocyanides with various aryl nitroalkenes have been investigated. When the aryl groups were XC_6H_4, naphthyl, and 2-pyridinyl, the reactions gave the 1-hydroxyindoles, 1-hydroxybenzoindoles, and 1-hydroxy-7-azaindole. When the aryl group was thienyl or furyl, fused 1-hydroxypyrroles were obtained. The reaction of isocyanide with methyl 2-nitro-2,4-pentadienoates gave 1-hydroxypyrroles. A mechanism involving the formation of an unstable oxazoline *N*-oxide which decomposes to the reaction products has been suggested.

The [1 + 4] cycloaddition reactions of isocyanides with electrophilic heterodienes are of interest for the synthesis of heterocyclic compounds. cycloaddition of isocyanides with *N*-acyl imines,[1] aza dienes,[2] diaza dienes,[3,4] α,β-unsaturated esters,[5] and α,β-unsaturated ketones,[6-8] particularly with diethylaluminium chloride as a catalyst,[9] were described. Saegusa et al.[10] suggested that the cycloaddition reaction of isocyanides with nitroalkenes **1** gave an initial cycloadduct, **2**. The ring opening of the unstable isoxazoline *N*-oxide **2**, with a hydrogen shift, gave the nitrile oxide **3** that was reduced by excess of isocyanide into 2-cyanoacetamide (Scheme I).[11] The replacement of a hydrogen atom by an alkyl or ester group in the 3-position

Scheme I



of **2** should change the process of evolution of the corresponding oxazoline *N*-oxide.[12] In this paper, we describe the results of the reaction of isocyanides **4** with various

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