Au(PPh₃)Cl–AgSbF₆-catalyzed rearrangement of propargylic 1,3-dithianes: formation of 8-membered 1,3-bisthio-substituted cyclic allenes[†]

Xia Zhao, Zhenzhen Zhong, Lingling Peng, Wenxiong Zhang and Jianbo Wang*

Received (in College Park, MD, USA) 13th February 2009, Accepted 4th March 2009 First published as an Advance Article on the web 27th March 2009 DOI: 10.1039/b903028j

Au(PPh₃)Cl-AgSbF₆-catalyzed rearrangement of propargylic 1,3-dithiane leads to the formation of 8-membered dithiosubstituted cyclic allenes, which are remarkably stable.

Au-catalyzed rearrangement of alkynes has attracted considerable attention in recent years. In particular, the Au-catalyzed rearrangement of propargyl acetate generates Au-carbene species through 1,2-acetoxy migration.¹ The Au-carbene species thus generated undergoes a variety of transformations.² Moreover, Au-catalyzed rearrangement of propargyl acetate to allene through 1,3-shift of the acetoxy group has recently been reported.³ We have focused our attention on Au-catalyzed reaction of propargylic sulfides and dithioacetals. These sulfur-containing substrates are converted into indene derivatives upon catalysis by the Au-complex, presumably through 1,2-sulfur migration and generation of a Au-carbene species (eqn (1)).⁴ As a continuation, we further studied the Au-catalyzed reaction of propargylic 1,3-dithianes. To our surprise, 1,3-bisthio-substituted cyclic allenes are isolated as the major product. The thio-substituted eight-membered allene thus obtained is stable and the structure has been fully characterized by spectra data and X-ray crystallographic analysis. Here we communicate the results of this investigation.



At the outset of this investigation, we examined rearrangement of propargylic 1,3-dithiane **1a** with various acid catalysts (Table 1). AuCl-catalyzed reaction of **1a** in 1,2-dichloroethane at 80 °C afforded cyclic allene **2a** in 67% isolated yield (entry 1). Surprisingly, **2a** is very stable—it remained unchanged at 100 °C under nitrogen atmosphere for more than one day without detectable decomposition. Its structure is fully characterized by spectra data and an X-ray

Notably, Au(PPh₃)Cl alone failed to catalyze the rearrangement of **1a**, while with only AgSbF₆ **2a** could be isolated in 57% yield. The combination of Au(PPh₃)Cl and AgOTf could afford **2a** in 50% isolated yield. Other transition metal catalysts were also examined. PtCl₂ failed to catalyze the reaction, while Zn(OTf)₂ decomposed **1a** without any detectable formation of **2a**. Finally, we examined protic acid catalysts. With HCl, TsOH, and TfOH, the reaction did not occur and starting material remained unchanged. However, **1a** partially decomposed when it was subjected to catalysis by BF₃·OEt₂. The catalytic system, Au(PPh₃)Cl-AgSbF₆ in 1,2-dichloroethane at 80 °C, was then applied to a range of propargylic

crystallographic analysis (vide infra). The yield of 2a could be

improved under catalysis by Au(PPh₃)Cl-AgSbF₆ (entry 2).

ethane at 80 °C, was then applied to a range of propargylic 1,3-dithianes **1b–g**. As shown in Table 2, the propargylic 1,3-dithianes with aromatic substituents all afforded the cyclic allene products in moderate to good yields. The only exception is when there is an alkyl substituent in the substrate, in which case the reaction under the same conditions gives a diene product **3** in 69% yield instead of a cyclic allene (entry 7). It is reasonable to assume that the cumulated double bonds of the initially formed cyclic allene isomerize to a diene due to the high ring-strain, while in products **2a–f** such isomerization is simply not possible.

 Table 1
 Acid-catalyzed reaction of 1a

$S \xrightarrow{Ph} Ph \xrightarrow{CICH_2CH_2CI} Ph \xrightarrow{Ph} Ph \xrightarrow{Ph} Ph$			
Entry	Cat. (5 mol%)	Time	Yield $(2a, \%)^a$
1	AuCl	30 min	67
2	Au(PPh ₃)Cl/AgSbF ₆	30 min	82
3	Au(PPh ₃)Cl	6 h	Trace ^b
4	AgSbF ₆	40 min	57
5	Au(PPh ₃)Cl/AgOTf	30 min	50
6	PtCl ₂	2 h	Trace ^b
7	$Zn(OTf)_2$	2 h	d
8	Aq. HCl	12 h	NR
9	TsOH	5 h	NR
10	TfOH	5 h	NR
11	$BF_3 \cdot OEt_2$	12 h	e

cat

^{*a*} Isolated yield after separation by column chromatography. ^{*b*} Trace amount of **2a** could be detected. Most starting material recovered. ^{*c*} NR: no reaction. Starting material recovered. ^{*d*} Decomposed. ^{*e*} Partially decomposed.

Beijing National Laboratory of Molecular Sciences (BNLMS) and Key Laboratory of Bioorganic Chemistry and Molecular Engineering of Ministry of Education, College of Chemistry, Peking University, 100871, Beijing, China

[†] Electronic supplementary information (ESI) available: Experimental details and spectra data for all new compounds. CCDC 720411 (2a) and 720412 (4). For ESI and crystallographic data in CIF or other electronic format see DOI: 10.1039/b903028j





Cyclic allenes have been an attractive class of molecules particularly because of the ring-strain when the allene unit is in a small ring system.⁵ Normal allenes have a linear C—C skeleton with orthogonal pairs of substituents. However, the C—C skeleton inevitably deviates from linearity when it is in a small ring system. The smallest reported all-carbon isolable cyclic allene is a 9-membered ring.^{6,7} When cyclic allenes contain heteroatoms such as oxygen,⁸ phosphorus,⁹ silicon¹⁰ or selenium,¹¹ the ring size can be smaller than their all-carbon counterpart. Kamigata and co-workers reported the preparation of 8-membered 1,3-bis-seleno cyclic allenes by the reaction of 1,3-dilithiated allenes with diselenides.¹¹ However, the attempt to prepare the sulfur analog failed with a similar method, presumably due to the higher ring-strain in the sulfur-containing cyclic allene.

Since the cyclic allenes obtained in our study seem to be the first eight-membered 1,3-bisthio-substituted cyclic allenes, we became interested in their structure, in particular the deviation of the allene unit from linearity. Fortunately, we could obtain a single crystal of **2a** (Fig. 1).¹² The X-ray analysis shows that the bond lengths of allene are almost normal. However, the two S(1)-C(1)-C(3)-S(2) planes are not perpendicular, being twisted by a torsion angle of 71°. For comparison, the corresponding angle is 75° in the seleno counterpart. Moreover, the cyclic allene framework is severely bent with a C1=C2=C3 angle of 162°, which is again smaller than the

corresponding angle in its diseleno cyclic allene analog (167°). Overall, the 8-membered 1,2-bisthio-substituted cyclic allene deviates more from linearity than its seleno counterpart. This is consistent with the sizes of sulfur and selenium—the smaller sulfur should make the 8-membered ring bear higher ring-strain.

To gain further insights into the structure of sulfur-containing cyclic allene, we attempted to derivatize **2a**. It was found that **2a** could be oxidized smoothly to the corresponding sulfone **4** by *m*CPBA (eqn (2)). The X-ray structure of **4** is shown in Fig. 2.¹³ Inspection of the X-ray structure reveals that the bond angle C(1)-C(2)-C(3) and torsion angle S(1)-C(3)-C(1)-S(2) are 170° and 76° , which are both larger than the corresponding angles in **2a**. These results indicate that the allene unit in **4** deviates less from normal allene geometry than the corresponding **2a**. This can be reasonably interpreted by the static electronic repulsion between the two sulfone groups, which counterbalances the ring strain.



Plausible mechanisms for the formation of cyclic allene are depicted in Scheme 1. We suggest two possible pathways. In the first case, metal carbene is the likely intermediate similar to the reaction mechanism of Au-catalyzed reaction of propargylic dithioacetals that we previously reported (pathway **A**). First, the 1,2-migration of one of the two thio groups through intermediate **I** generates the metal carbene species **II**. From Au carbene intermediate **II**, 1,2-sulfur shift affords the cyclic allene product.¹⁴ We assume that for the Au carbene intermediate, sulfur group migration is easier than aromatic C–H insertion to give indene. However, in the case of propargylic dithioacetals, 1,2-sulfur shift becomes difficult because it produces a highly strained 7-membered cyclic allene. This explains the different reaction pathways shown in eqn (1).

An alternative mechanism for the cyclic allene formation is the direct attack of the sulfur on the remote alkyne carbon to afford the gold σ -allyl cation such as **IV** (pathway **B**). Subsequent release of the Au catalyst gives the cyclic allene product.

Cavallo and co-workers have recently studied the mechanism of 1,3-migration of acetoxy in Au-catalyzed reaction of propargylic acetate.¹⁵ Based on the results of theoretical



pathway A



pathway **B**



Scheme 1 Possible reaction pathways.

calculation, they have suggested a mechanism of double 1,2-acetoxy migrations that accounts for the formal 1,3-migration of the acetoxy group. In view of this study, we consider that double 1,2-sulfur migrations are more likely in our reaction (pathway **A**), although further investigation is needed to unambiguously differentiate the two reaction pathways.

In conclusion, we have reported a novel rearrangement of propargylic dithioacetals catalyzed by $Au(PPh_3)Cl/AgSbF_6$, which affords 1,3-bisthio-substituted cyclic allenes in good yields. To the best of our knowledge, this is the first example of 8-membered 1,3-bisthio-substituted cyclic allenes. The remarkable stability of the cyclic allenes allows us to inspect their structure in detail, which adds useful information on the family of hetero atom substituted cyclic allenes.

The project is generously supported by NSFC (Grant No. 20832002, 20772003, 20821062), the Ministry of Education of China, and the National Basic Research Program of China (973 Program, No. 2009CB825300).

Notes and references

 For recent reviews, see: (a) S. Ma, S. Yu and Z. Gu, Angew. Chem., Int. Ed., 2006, 45, 200; (b) A. S. K. Hashmi and C. J. Hutchings, Angew. Chem., Int. Ed., 2006, 45, 7896; (c) E. Jiménez-Núñez and A. M. Echavarren, Chem. Commun., 2007, 333; (d) A. Fürstner and P. W. Davies, Angew. Chem., Int. Ed., 2007, 46, 3410; (e) A. S. K. Hashmi, *Chem. Rev.*, 2007, **107**, 3180; (f) Z. Li, C. Brouwer and
C. He, *Chem. Rev.*, 2008, **108**, 3239; (g) A. Arcadi, *Chem. Rev.*, 2008, **108**, 3266; (h) E. Jiménez-Núñez and A. M. Echavarren, *Chem. Rev.*, 2008, **108**, 3326; (i) D. J. Gorin, B. B. D. Sherry and
F. D. Toste, *Chem. Rev.*, 2008, **108**, 3351.

- 2 For a seminal report, see: V. Rautenstrauch, J. Org. Chem., 1984, **49**, 950.
- 3 For Au-catalyzed propargyl acetate rearrangement to allene, see: (a) L. Zhang, J. Am. Chem. Soc., 2005, 127, 16804; (b) S. Wang and L. Zhang, J. Am. Chem. Soc., 2006, 128, 8414; (c) A. Buzas and F. Gagosz, J. Am. Chem. Soc., 2006, 128, 12614; (d) A. Buzas, F. Istrate and F. Gagosz, Org. Lett., 2006, 8, 1957; (e) N. Marion, S. Díez-González, P. de Frémont, A. R. Noble and S. P. Nolan, Angew. Chem., Int. Ed., 2006, 45, 3647. For Ag-catalyzed [3,3] rearrangement of propargyl acetate, see: (f) A. W. Sromek, A. V. Kel'in and V. Gevorgyan, Angew. Chem., Int. Ed., 2004, 43, 2280.
- 4 L. Peng, X. Zhang, S. Zhang and J. Wang, J. Org. Chem., 2007, 72, 1192.
- 5 For reviews on cyclic allenes, see: (a) M. Christl, in Modern Allene Chemistry, ed. N. Krause and A. S. K. Hashmi, Wiley-VCH, Weinheim, 2004, pp. 243; (b) R. P. Johnson, Chem. Rev., 1989, 89, 1111. For strain estimates for cyclic allenes, see: (c) K. J. Daoust, S. M. Hernandez, K. M. Konrad, I. D. Mackie, J. Winstanley, Jr and R. P. Johnson, J. Org. Chem., 2006, 71, 5708.
- 6 A. T. Blomquist, L. H. Liu and J. C. Bohrer, J. Am. Chem. Soc., 1952, 74, 3643.
- 7 For recent studies on the reaction of 9-membered cyclic allenes, see; (a) T. Bai, P. Xue, L. Zhang, S. Ma and G. Jia, *Chem. Commun.*, 2008, 2929; (b) I. Erden, W. Cao, M. Price and M. Colton, *Tetrahedron*, 2008, 64, 5497; (c) M. Ogasawara, A. Okada, K. Nakajima and T. Takahashi, *Org. Lett.*, 2009, 11, 177.
- 8 S. Harusawa, H. Moriyama, N. Kase, H. Ohishi, R. Yoneda and T. Kurihara, *Tetrahedron*, 1995, **51**, 6475.
- 9 M. A. Hofmann, U. Bergsträßer, G. J. Reiß, L. Nyulászi and M. Regitz, Angew. Chem., Int. Ed., 2000, 39, 1261.
- 10 (a) Y. Pang, S. A. Petrich, V. G. Young Jr, M. S. Gordon and T. J. Barton, J. Am. Chem. Soc., 1993, 115, 2534; (b) F. Hojo and W. Ando, Synlett, 1995, 880.
- 11 (a) T. Shimizu, D. Miyasaka and N. Kamigata, J. Org. Chem., 2001, 66, 1787; (b) T. Shimizu, K. Sakamaki, D. Miyasaka and N. Kamigata, J. Org. Chem., 2000, 65, 1721.
- 12 Crystal data for **2a**: $[C_{18}H_{16}S_2]$, M = 296.43, monoclinic, space group $P2_1/n$, a = 10.491(2), b = 8.7754(18), c = 17.309(4) Å, $\beta = 104.25(3)$, V = 1544.4(5) Å³, Z = 4, T = 293(2) K, $\mu = 0.332$ mm⁻¹, reflections collected/unique 10 549/3511 [*R*(int) = 0.0313]. Final R indices [$I > 2 \sigma(I)$] R1 = 0.0404. wR2 = 0.0946. CCDC 720411.
- 13 For 4: $[C_{18}H_{16}O_4S_2]$, M = 360.43, monoclinic, space group $P_{2_1/c}$, a = 11.306(2), b = 10.818(2), c = 14.594(3) Å, $\beta = 111.03(3)$, V = 1666.1(6) Å³, Z = 4, T = 293(2) K, reflections collected/ unique 15234/3821 [*R*(int) = 0.0466]. Final *R* indices [$I > 2\sigma(I)$] R1 = 0.0384. wR2 = 0.0947. CCDC 720412.
- 14 For a study on 1,2-sulfur shifts in Rh(II) carbene reaction, see: F. Xu, W. Shi and J. Wang, J. Org. Chem., 2005, **70**, 4191.
- 15 A. Correa, N. Marion, L. Fensterbank, M. Malacria, S. P. Nolan and L. Cavallo, *Angew. Chem., Int. Ed.*, 2008, **47**, 718.