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Gold-Catalyzed Cascade Reaction of Hydroxy Enynes for the Synthesis of Oxanorbornenes and Naphthalene Derivatives

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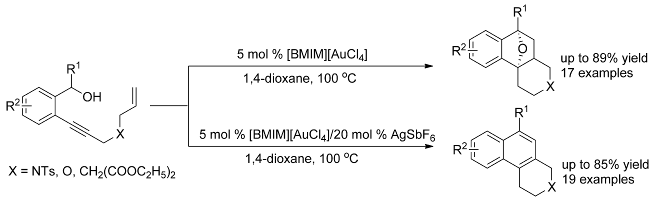
ABSTRACT



An efficient and selective gold-catalyzed cascade reaction for the synthesis of oxanorbornenes and naphthalene derivatives from easily prepared hydroxy enynes has been developed. Divergent products could be obtained from the same substrates by different gold catalytic systems.

Electrophilic metal-catalyzed tandem reactions are the most powerful tools for the efficient construction of complicated molecular frameworks in a one-pot operation.[1] In contrast to multistep reactions, one-pot processes have obvious advantages that greatly improve synthetic efficiency and generate less chemical waste. In recent years, the oxycyclization of alkynol coupling with another functional group is a very important strategy because of the rapid assembly of different heterocyclic systems. Moreover, incorporation of this oxycyclization strategy has been highlighted in the synthesis of natural products.[3] Thus, the exploration of a novel, efficient, and atom-economical tandem reaction in this area still needs to be actively pursued. In this context, gold complexes or salts as promising catalysts provide an excellent tool for the construction of the carbon- and heterocyclic compounds with high

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(1) (a) Tietze, L. F. *Chem. Rev.* **1996**, *96*, 115. (b) Wasilke, J.-C.; Obrey, S. J.; Baker, R. T.; Bazan, G. C. *Chem. Rev.* **2005**, *105*, 1001. (c) Nicolaou, K. C.; Edmonds, D. J.; Bulger, P. G. *Angew. Chem., Int. Ed.* **2006**, *45*, 7134. (d) Dondoni, A.; Massi, A. *Acc. Chem. Res.* **2006**, *39*, 451. (e) D'Souza, D. M.; Müller, T. J. J. *Chem. Soc. Rev.* **2007**, *36*, 1095. (f) Shindoh, N.; Takemoto, Y.; Takasu, K. *Chem.—Eur. J.* **2009**, *15*, 12168. (g) Zhou, J. *Chem.—Asian J.* **2010**, *5*, 422.

(2) For some selected examples, see: (a) Zhang, L.; Kozmin, S. A. *J. Am. Chem. Soc.* **2005**, *127*, 6962. (b) Belting, V.; Krause, N. N. *Org. Lett.* **2006**, *8*, 4489. (c) Liu, B.; De Brabander, J. K. *Org. Lett.* **2006**, *8*, 4907. (d) Diéguez-Vázquez, A.; Tzschucke, C. C.; Lam, W. Y.; Ley, S. V. *Angew. Chem., Int. Ed.* **2008**, *47*, 209. (e) Fañanás, F. J.; Fernández, A.; Cevic, D.; Rodríguez, F. *J. Org. Chem.* **2009**, *74*, 932. (f) Barluenga, J.; Fernández, A.; Rodríguez, F.; Fañanás, F. J. *J. Organomet. Chem.* **2009**, *694*, 546. (g) Barluenga, J.; Fernández, A.; Rodríguez, F.; Fañanás, F. J. *Chem.—Eur. J.* **2009**, *15*, 8121. (h) Barluenga, J.; Fernández, A.; Diéguez, A.; Rodríguez, F.; Fañanás, F. J. *Chem.—Eur. J.* **2009**, *15*, 11660. (i) Patil, N. T.; Kavthe, R. D.; Raut, V. S.; Shinde, V. S.; Sridhar, B. *J. Org. Chem.* **2010**, *75*, 1277. (j) Patil, N. Y.; Singh, V.; Konala, A.; Mutyala, A. K. *Tetrahedron Lett.* **2010**, *51*, 1493. (k) Patil, N. T.; Konala, A. *Eur. J. Org. Chem.* **2010**, 6831. (l) Liu, L.-P.; Hammond, G. B. *Org. Lett.* **2010**, *12*, 4640. (m) Alcaide, B.; Almendros, P.; Carrascosa, R.; Torres, M. R. *Adv. Synth. Catal.* **2010**, *352*, 1277. (n) Alcaide, B.; Almendros, P.; Carrascosa, D.-C. R. *Chem.—Eur. J.* **2011**, *17*, 4968.

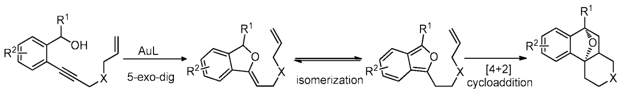
(3) (a) Brooks, C. J. W.; Watson, D. G. *Nat. Prod. Rep.* **1985**, *2*, 427. (b) Boumenjel, A. *Curr. Med. Chem.* **2003**, *10*, 2621. (c) Morimoto, M.; Fukumoto, H.; Nozoe, T.; Hagiwara, A.; Komai, K. J. *Agric. Food Chem.* **2007**, *55*, 700.

10.1021/ol301322a

atom-economy and mild conditions in modern organic chemistry.[4] Recently, an intermolecular cascade cycloisomerization/Diels–Alder reaction catalyzed by gold to form polycyclic compounds has been reported by Barluenga.[5] The sequences went through the exo- or endo-cycloisomerization and finally generated the polycyclic products by Diels–Alder reaction.

Inspired by this intriguing study and in continuation of our work on the synthesis of heterocyclic compounds,[6] we envisioned that the treatment of the easily prepared hydroxy enynes with gold catalyst would generate interesting oxanorbornenes (scheme 1), which are very valuable synthetic intermediates in a huge number of ring-opening reactions to the synthesis of biologically active compounds.[7] This process would involve an initial 5-*exo*-*dig* cyclization to form an enol ether intermediate in a highly regioselective manner,[8] which may be in equilibrium with isobenzofuran,[9] and then followed a Diels–Alder reaction. To our surprise, besides the desired oxanorbornene compound, a naphthalene compound was also formed. To the best of our knowledge, such cascade reactions have rarely been reported in the literature.[9,10] Herein, we report a successful realization of this hypothesis and the details of our discovery.

Scheme 1. Proposed Tandem Catalytic 5-*Exo-Dig* Cycloisomerization/Diels–Alder Reaction



Initially, optimization studies of this transformation started with hydroxy enyne **1a** as the model substrate (Table 1 and Table S1 in the Supporting Information). To our delight, **1a** in the presence of 5 mol % of $PicAuCl_2$ in 1,4-dioxane at 100 °C gave an oxanorbornene product epoxybenzo[*f*]isoquinoline **2a** in 65% yield after 2 h (entry 1). A variety of gold catalysts were then screened, and $[BMIM][AuCl_4]$[11] was proven to be the most efficient (entries 2–5). When $[BMIM]AuCl_4$ loading was decreased from 5 to 2.5 mol %, the yield was decreased (entry 6). Other solvents such as THF, MeCN, and toluene were found to be less effective (see the Supporting Information). When we decreased the temperature to room temperature, a mainly 5-*exo*-*dig* cyclization product **4a** was obtained (entry 7). $[BMIM]AuCl_4/AgSbF_6$ was also applied to the reaction, but no better result was obtained and a trace amount of **3a** was detected by ^1H NMR spectroscopy (entry 8). Subsequently, the stepwise addition of $[BMIM]AuCl_4$ and $AgSbF_6$ to the reaction mixture was investigated (entry 9). Unexpectedly, **2a** was not detected, but a naphthalene product tetrahydrobenzo[*f*]isoquinoline **3a** was isolated in 81% yield after 4 h. Neither changing Ag sources nor temperature could obviously improve the yield of **3a** (see the Supporting Information). Compared with the Lewis acid system, Brønsted acid *p*-TsOH was less reactive and afforded lower yields of the product **3a** (entry 11). Thus, the use of $[BMIM]AuCl_4$ (5 mol %) in 1,4-dioxane at 100 °C was considered to be an optimal reaction condition to form **2a** (conditions A), and the stepwise addition of $[BMIM]AuCl_4$ (5 mol %) and $AgSbF_6$ (20 mol %) in 1,4-dioxane at 100 °C was found to be the most efficient and was selected as the standard set of conditions for **3a** (conditions B).

To define the scope of the tandem reaction, we next turned our attention to the construction of oxanorbornenes under the optimal conditions A. Various *N*-tethered, *O*-tethered, and *C*-tethered hydroxy enynes were

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[4] For recent selected reviews on gold-catalyzed reactions, see: (a) Gorin, D. J.; Toste, F. D. *Nature* **2007**, *446*, 395. (b) Hashmi, A. S. K. *Chem. Rev.* **2007**, *107*, 3180. (c) Fürstner, A.; Davies, P. W. *Angew. Chem., Int. Ed.* **2007**, *46*, 3410. (d) Arcadi, A. *Chem. Rev.* **2008**, *108*, 3266. (e) Li, Z.; Brouwer, C.; He, C. *Chem. Rev.* **2008**, *108*, 3239. (f) Jiménez-Núñez, E.; Echavarren, A. M. *Chem. Rev.* **2008**, *108*, 3326. (g) Gorin, D. J.; Sherry, B. D.; Toste, F. D. *Chem. Rev.* **2008**, *108*, 3351. (h) Hashmi, A. S. K.; Rudolph, M. *Chem. Soc. Rev.* **2008**, *37*, 1766. (i) Hashmi, A. S. K. *Angew. Chem., Int. Ed.* **2010**, *49*, 5232. (j) Corma, A.; Leyva-Pérez, A.; Sabater, M. J. *Chem. Rev.* **2011**, *111*, 1657. (k) Norbert, K.; Christian, W. *Chem. Rev.* **2011**, *111*, 1994. (l) Xiao, J.; Li, X. *Angew. Chem., Int. Ed.* **2011**, *50*, 7226. (m) Alcaide, B.; Almendros, P.; Alonso, J. M. *Org. Biomol. Chem.* **2011**, *9*, 4405. (n) Alcaide, B.; Almendros, P.; Alonso, J. M. *Molecules* **2011**, *16*, 7815. (o) Bandini, M. *Chem. Soc. Rev.* **2011**, *40*, 1358. (p) Rudolph, M.; Stephen, A.; Hashmi, K. *Chem. Soc. Rev.* **2012**, *41*, 2448.

[5] Barluenga, J.; Calleja, J.; Mendoza, A.; Rodríguez, F.; Fañanás, F. J. *Chem.—Eur. J.* **2010**, *16*, 7110.

[6] (a) Lu, L.; Liu, X.-Y.; Shu, X.-Z.; Yang, K.; Ji, K.-G.; Liang, Y.-M. *J. Org. Chem.* **2009**, *74*, 474. (b) Niu, Y.-N.; Yan, Z.-Y.; Gao, G.-L.; Wang, H.-L.; Shu, X.-Z.; Ji, K.-G.; Liang, Y.-M. *J. Org. Chem.* **2009**, *74*, 2893. (c) Xie, Y.-X.; Yan, Z.-Y.; Qian, B.; Deng, W.-Y.; Wang, D.-Z.; Wu, L.-Y.; Liu, X.-Y.; Liang, Y.-M. *Chem. Commun.* **2009**, 5451. (d) Shu, X.-Z.; Zhao, S.-C.; Ji, K.-G.; Zheng, Z.-J.; Liu, X.-Y.; Liang, Y.-M. *Eur. J. Org. Chem.* **2009**, 117.

[7] (a) Ikoma, M.; Oikawa, M.; Gill, M. B.; Swanson, G. T.; Sakai, R.; Shimamoto, K.; Sasaki, M. *Eur. J. Org. Chem.* **2008**, 5215. (b) Schindler, C. S.; Diethelm, S.; Carreira, E. M. *Angew. Chem., Int. Ed.* **2009**, *48*, 6296. (c) Claeys, D. D.; Stevens, C. V.; Roman, B. I.; De Caveye, P. V.; Waroquierb, M.; Van Speybroeck, V. *Org. Biomol. Chem.* **2010**, *8*, 3644.

[8] For the cycloisomerization of 2-(ethynyl)benzyl alcohol to form 5-exodig cyclization product, see: (a) Villemin, D.; Goussu, D. *Heterocycles* **1989**, *29*, 1255. (b) Padwa, A.; Krumpe, K. E.; Weingarten, M. D. *J. Org. Chem.* **1995**, *60*, 5595. (c) Khan, M. W.; Kundu, N. G. *Synlett* **1999**, 456. (d) Hiroya, K.; Jouke, R.; Kameda, M.; Yasuhara, A.; Sakamoto, T. *Tetrahedron* **2001**, *57*, 9697. (e) Lu, W.-D.; Lin, C.-F.; Wang, C.-J.; Wang, S.-J.; Wu, M.-J. *Tetrahedron* **2002**, *58*, 7315. (f) Bacchi, A.; Costa, M.; Cá, N. D.; Fabbricatore, M.; Fazio, A.; Gabriele, B.; Nasi, C.; Salerno, G. *Eur. J. Org. Chem.* **2004**, 574. (g) Berg, T. C.; Bakken, V.; Gundersen, L.-L.; Petersen, D. *Tetrahedron* **2006**, *62*, 6121. (h) Hashmi, A. S. K.; Schäfer, S.; Wölfle, M.; Gil, C. D.; Fischer, P.; Laguna, A.; Blanco, M. C.; Gimeno, M. C. *Angew. Chem., Int. Ed.* **2007**, *46*, 6184. (i) Yu, X.; Seo, S. Y.; Marks, T. J. *J. Am. Chem. Soc.* **2007**, *129*, 7244. (j) Seo, S. Y.; Yu, X.; Marks, T. J. *J. Am. Chem. Soc.* **2009**, *131*, 263. (k) Peng, P.; Tang, B.-X.; Pi, S.-F.; Liang, Y.; Li, J.-H. *J. Org. Chem.* **2009**, *74*, 3569. (l) Zanardi, A.; Mata, J. A.; Peris, E. *Organometallics* **2009**, *28*, 4335. (m) Praveen, C.; Iyyappan, P.; Perumal, P. T. *Tetrahedron Lett.* **2010**, *51*, 4767. (n) Mancuso, R.; Mehta, S.; Gabriele, B.; Salerno, G.; Jenks, W. S.; Larock, R. C. *J. Org. Chem.* **2010**, *75*, 897.

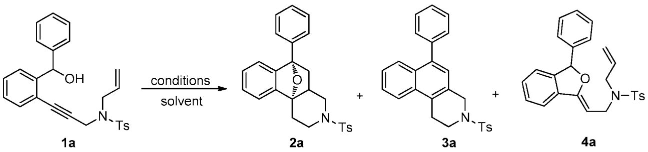
[9] Gabriele, B.; Salerno, G.; Fazio, A.; Pittelli, R. *Tetrahedron* **2003**, *59*, 6251.

[10] (a) Asao, N.; Takahashi, K.; Lee, S.; Kasahara, T.; Yamamoto, Y. *J. Am. Chem. Soc.* **2002**, *124*, 12650. (b) Asao, N; Nogami, T.; Lee, S.; Yamamoto, Y. *J. Am. Chem. Soc.* **2003**, *125*, 10921. (c) Asao, N.; Sato, K.; Menggenbateer; Yamamoto, Y. *J. Org. Chem.* **2005**, *70*, 3682. (d) Asao, N.; Sato, K. *Org. Lett.* **2006**, *8*, 5361. (e) Menon, S.; Sinha-Mahapatra, D.; Herndon, J. W. *Tetrahedron* **2007**, *63*, 8788. (f) Kumar Patti, R.; Duan, S.; Camacho-Davila, A.; Waynant, K.; Dunn, K. A.; Herndon, J. W. *Tetrahedron Lett.* **2010**, *51*, 3682.

[11] The preparation for $[BMIM][AuCl_4]$, see: Hasan, M.; V. Kozhevnikov, I.; Siddiqui, M. R. H.; Steiner, A.; Winterton, N. *Inorg. Chem.* **1999**, *38*, 5637.

investigated (Table 2). In most cases, the desired products were generated in moderate to good yields. When R^1 were aryl groups, the electron-withdrawing groups gave results superior to those with an electron-donating aryl groups (entries 2–7). In addition, the corresponding products were not separated except for **1g**, and unexpectedly, the corresponding naphthalene compounds were only obtained in low yield when *N*-tethered and *O*-tethered hydroxy enynes containing a methoxy group were on the *para*-position of rgw aryl group (R^1) (entries 5, 19, and 20), which might be due to the lower stability of the corresponding oxacyclic structure.[12] When R^1 was an alkyl group or H, the desired products were also obtained in high yields (entries 13–16). The vinyl and phenylethynyl in R^1 also gave good yields of **2k** and **2l**, respectively (entries 11 and 12). The structure of **2l** was confirmed by X-ray crystal structure analysis (see the Supporting Information). Under the standard reaction conditions, the substituted parent phenyl rings with **F** or **Cl** functionalities in R^2 were compatible for this transformation in good yields (entries 8 and 9), but when the substituent was a methyl, the desired product was not examined (entry 10). Hydroxy enyne **1n** without the fused aromatic rings successfully participated in this cascade reaction to generate the desired product **2n** in 32% yield (entry 17).

Table 1. Optimization of Reaction Conditions[a]

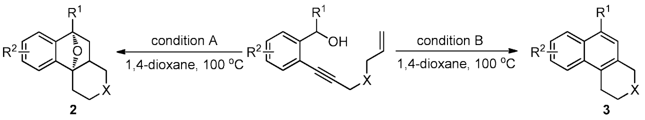


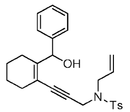
entry	catalyst (mmol %)	solvent	time (h)	yield[b] (%)	
				2a	**3a**
1	$PicAuCl_2$ (5)[c]	1,4-dioxane	2	65	
2	PPh_3AuCl (5)	1,4-dioxane	2		
3	$AuCl_3$ (5)	1,4-dioxane	2	60	
4	$HAuCl_4.2H_2O$ (5)	1,4-dioxane	2	69	
5	$LAuCl_4$(5)[d]	1,4-dioxane	2	75	
6	$LAuCl_4$ (2.5)	1,4-dioxane	2	50	
7[e]	$LAuCl_4$ (5)	1,4-dioxane	2	46[f]	
8[g]	$LAuCl_4$(5)/$AgSbF_6$ (20)	1,4-dioxane	2	25	<5
9[h]	$LAuCl_4$ (5)/$AgSbF_6$ (20)	1,4-dioxane	4		81
10[h]	$LAuCl_4$ (5)/$AgSbF_6$ (10)	1,4-dioxane	4	<5	70
11[h]	$LAuCl_4$ (5) /*p*-TsOH (20)	1,4-dioxane	4		45

[a] Unless otherwise noted, all reactions were performed with 0.1 mmol of **1a** in solvent (1.0 mL) at 100 °C. [b] Isolated yields. [c] Pic = picolinate. [d] L = BMIM, BMIM = 1-butyl-3-methylimidazolium. [e] At room temperature. [f] The yield of the 5-*exo-dig* cyclization product **4a**. [g] A solution of $LAuCl_4$ and $AgSbF_6$ in 1,4-dioxane was stirred at room temperature for 10 min. [h] The reaction was stirred at 100 °C for 2 h with [BMIM]$AuCl_4$ until most of the **1a** was converted to product **2a**, and then AgX (X = SbF_6, BF_4, OTf) or *p*-TsOH was added and the mixture was heated to 100 °C.

The role of the gold catalyst in the Diels–Alder cycloaddition step was also investigated. The 5-*exo-dig* cyclization product **4a** was isolated in the presence of 5 mol % [BMIM]$AuCl_4$ at room temperature. We observed that the treatment of **4a** in the absence of gold catalyst at 100 °C (the same condition) resulted only a small amounts of the oxanorbornene **2a** (10% yield). The result demonstrated that gold catalyst could accelerate the Diels–Alder reaction.

Table 2. Synthesis of Oxanorbornenes and Naphthalene Derivatives via Gold Catalyst from Hydroxy Enynes[a]



entry	substrate	products/yield (%)[b]	
		2	**3**
1	$R^1 = C_6H_5$, $R^2 = H$, X = NTs	**2a**/75	**3a**/81
2	$R^1 =$ *p*- MeC_6H_4, $R^2 = H$, X = NTs	**2b**/61	**3b**/62
3	$R^1 =$ *m*-MeC_6H_4, $R^2 = H$, X = NTs	**2c**/70	**3c**/72
4	$R^1 =$ *o*-MeC_6H_4, $R^2 = H$, X = NTs	**2d**/72	**3d**/70
5	$R^1 =$ *p*-$OMeC_6H_4$, $R^2 = H$, X = NTs	**2e**/18[c, d]	**3e**/79
6	$R^1 =$ *p*-FC_6H_4, $R^2 = H$, X = NTs	**2f**/89	**3f**/85
7	$R^1 =$ 2,6-DiMe-4-$OMeC_6H_4$, $R^2 = H$, X = NTs	**2g**/40[d]	**3g**/80
8	$R^1 = H$, $R^2 =$ 5-F, X = NTs	**2h**/87	**3h**/70
9	$R^1 = H$, $R^2 =$ 4-Cl, X = NTs	**2i**/80	**3i**/67
10	$R^1 = H$, $R^2 =$ 4-Me, X = NTs	**2j**/trace[e]	**3j**/trace[e]
11	$R^1 =$ phenylethynyl, $R^2 = H$, X = NTs	**2k**/73	**3k**/55
12	$R^1 =$ vinyl, $R^2 = H$, X = NTs	**2l**/81[d]	**3l**/trace[e]
13	$R^1 = H$, $R^2 = H$, X = NTs	**2m**/87[d]	**3m**/18
14	$R^1 = C_2H_5$, $R^2 = H$, X = NTs	**2n**/84	**3n**/48
15	$R^1 = C_5H_{11}$, $R^2 = H$, X = NTs	**2o**/74	**3o**/47
16	$R^1 = C_6H_{11}$, $R^2 = H$, X = NTs	**2p**/84	**3p**/70
17		**2q**/32	**3q**/30
18	$R^1 = C_6H_5$, $R^2 = H$, X = O	**2r**/13	**3r**/60
19	$R^1 =$ *p*-$OMeC_6H_4$,$R^2 = H$, X = O	**2s**/24[c]	**3s**/46
20	$R^1 =$ 2,6-DiMe-4-$OMeC_6H_4$, $R^2 = H$, X = O	**2t**/35[c]	**3t**/42
21	$R^1 = C_6H_5$, $R^2 = H$, X = $C(CO_2C_2H_5)_2$	**2u**/72	**3u**/66

[a] Unless otherwise noted, all reactions were performed with 0.1 mmol of **2**. Conditions A: 5 mol % of [BMIM]$AuCl_4$, 2.0 h. Conditions B: 5 mol % of [BMIM]$AuCl_4$, 2.0 h, then $AgSbF_6$ (20 mol %), 2.0 h. [b] Isolated yield. [c] The yield stands for the corresponding product **3**. [d] For 2.5 h. [e] No detected.

We next examined the scope of this new approach for the synthesis of naphthalene derivatives **3** (Table 2). Starting materials hydroxy enynes **1a–u** were also investigated under the standard conditions B. We found that **1a–i**,**k**, **m–u** underwent cascade processes efficiently and formed the corresponding products **3a–i**,**k**,**m–u** in moderate to good yields (entries 1–9, 11, and 13–21). The structure of **3h** was also confirmed by X-ray crystal struture analysis (see the Supporting Information). In contrast to product **2**, when R^1 was a straight-chain alkyl group or H, the corresponding yields were not good (entries 13–15), which

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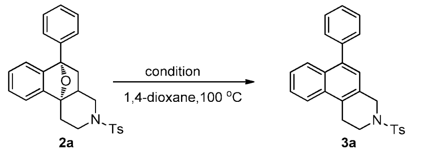
[12] (a) Padwa, A.; Brodney, M. A.; Dimitroff, M. *J. Org. Chem.* **1998**, *63*, 5304. (b) Ginn, J. D.; Lynch, S. M.; Padwa, A. *Tetrahedron Lett.* **2000**, *41*, 9387. (c) Padwa, A.; Ginn, J. D.; Bur, S. K.; Eidell, C. K.; Lynch, S. M. *J. Org. Chem.* **2002**, *67*, 3412. (d) Padwa, A.; Ginn, J. D. *J. Org. Chem.* **2005**, *70*, 5197.

might be due to the formation of carbocation intermediate **E** (Scheme 3).[13] Moreover, the results in Table 2 revealed the fact that Ag sources play an important role in enhancing the yield of **3**, as well as accelerating the conversion of **2** into **3** (entries 1, 5, 19, and 20). Not surprisingly, when R^1 was a vinyl group, the corresponding product was not afforded under condition **B** (entry 12). It was found that, in most cases, *N*-tethered hydroxy enynes afforded better results than *O*-tethered and *C*-tethered hydroxy enynes in this cascade reaction.

To explore the mechanism of the tandem reactions, we found that the ring-opening of **2a** was induced by different catalytic systems, the product **3a** could only be obtained in the presence of 5 mol % of [BMIM]$AuCl_4$ and 20 mol % of $AgSbF_6$ (Scheme 2). The results clearly demonstrated that the formation of naphthalene **3a** should use [BMIM]$AuCl_4$ with $AgSF_6$ as a cocatalyst in the tandem reactions. Moreover, the addition of $AgSF_6$ was not only intended to act as a scavenger for chloride, but also the presence of silver can influence the gold cation reactivity.[14]

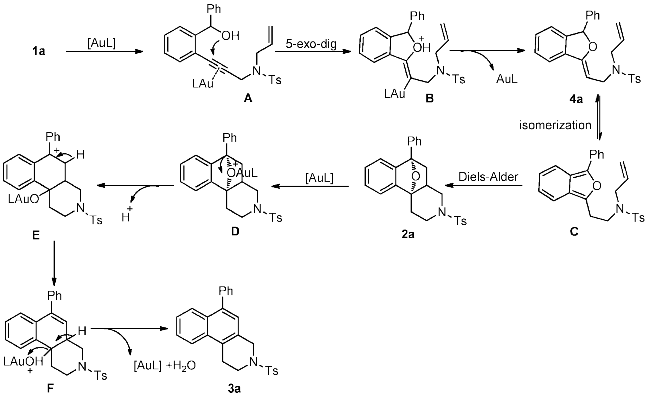
Scheme 2. Controlled Experiments



condition 1: 5 mol % [BMIM][$AuCl_4$]	yield = 0%, 4 h
condition 2: 20 mol % $AgSbF_6$	yield = 0%, 4 h
condition 3: 5 mol % [BMIM][$AuCl_4$]/20 mol % $AgSbF_6$	yield = 95%, 2 h
condition 4: 5 mol % [BMIM][$AuCl_4$]/20 mol % $AgSbF_6$ and celite filtration	yield = 0%, 2 h

On the basis of the above investigations, a plausible mechanism for this transformation was proposed in Scheme 3. Initially, the coordination of the alkynyl moiety of hydroxy enyne **1a** with gold catalyst gives the complex **A**, which followed subsequent 5-*exo-dig* cyclization to generate species **B**. **B** undergoes protonation to generate intermediate **4a**, which might be in equilibrium with isobenzofuran **C** and followed concomitant intramolecular Diels–Alder reaction to afford the product **2a**. Then, the oxanorbornene product **2a** goes through ring-opening induced by gold catalyst to form the species **E**, which undergoes protonation and then dehydrates to produce **3a**.

Scheme 3. Proposed Mechanisms of the Gold-Catalyzed Tandem Reaction



In summary, we have developed an efficient gold-catalyzed cascade reaction for the construction of oxanorbornenes and naphthalene derivatives from easily prepared hydroxy enynes. The sequences involve a highly regioselective 5-*exo-dig* cycloisomerisation, followed by a Diels–Alder reaction to afford oxanorbornenes. With the same hydroxy enynes, we also obtained naphthalene derivatives using a different catalytic system by further aromatization reaction. Gold catalysts are effective to catalyze all three processes in this tandem reaction. The value of this cascade reaction is reflected by the applicability of diverse alcohol substrates and operational simplicity.

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Supporting Information Available. Detailed experimental procedure, copies of ^1H NMR and ^{13}C NMR spectra of all compounds, and X-ray data for **2l** and **3h** (CIF). This material is available free of charge via the Internet at http://pubs.acs.org.

The authors declare no competing financial interest.

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(13) Hsu, Y.-C.; Datta, S.; Ting, C.-M.; Liu, R.-S. *Org. Lett.* **2008**, *10*, 521.

(14) Wang, D.; Cai, R.; Sharma, S.; Jirak, J.; Thummanapelli, S. K.; Akhmedov, N. G.; Zhang, H.; Liu, X.; Petersen, J. L.; Shi, X. *J. Am. Chem. Soc.* **2012**, *134*, 9012. (b) The experimental procedure of conditions 4: A solution of 5 mol % of [BMIM][$AuCl_4$]/20 mol % of $AgSbF_6$ in 1,4-dioxane was stirred at room temperature for 10 min, and then AgCl was removed by Celite filtration.