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$PtCl_2$-Catalyzed Rearrangement of Methylenecyclopropanes

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Activation of π-bonds with catalytic amounts of carbophilic transition metal cations, most notably Pt^{II}, Au^{I}, or Au^{III}, constitutes a formidable trigger for a host of skeletal rearrangement reactions.[1] Transformations of this type are simple, safe, and convenient to perform and usually result in a significant increase in structural complexity. While the reactivity of alkynes and enynes in the presence of such catalysts has already been investigated in considerable detail,[1] the behavior of alkenes is far less understood. Various recent examples of Pt- or Au-catalyzed addition reactions to unactivated olefins, however, provide encouraging leads for further investigations.[2]

As part of our ongoing studies in this field,[3] we identified alkylidenecyclopropanes[4] as a potentially useful class of substrates. It was anticipated that coordination of a soft cation to their double bond might engender productive isomerizations driven by the release of ring strain. Although many different reactions of alkylidenecyclopropanes induced by noble metal- or Lewis-acid catalysts are already known in the literature,[5] most notably their conversion into homoallylic products, it was hoped that other conceivable scenarios might be realized that have little or no precedence.[6]

We were pleased to see that treatment of compound **3** with catalytic amounts of $PtCl_2$ in toluene resulted in the clean formation of cyclobutene **4** (Scheme 1).[7] In line with previous findings from our group, the reaction was significantly accelerated when performed under an atmosphere of CO.[8] Under these conditions, the catalyst loading can be reduced to 1 mol %, providing product **4** in 77% isolated yield. Table 1 shows the scope of this transformation which is applicable to alkylidenecyclopropanes with either aliphatic or aromatic substituents at the double bond. Electron-withdrawing as well as electron-donating substituents are well accommodated. It is also worth mentioning that the substrates were conveniently formed by a new variant of the Julia−Kocienski olefination,[9] simply on exposure of the corresponding aldehyde to cyclopropyl sulfone **2** and Cs_2CO_3 in THF/DMF at 70 °C. Since the olefination occurs under Barbier conditions and no separate deprotonation step is necessary,[10] this procedure is highly user friendly. For details, consult the Supporting Information.

A tentative mechanism for the observed cyclobutene formation is depicted in Scheme 2. One of the possible resonance structures of the complex formed by coordination of Pt(2+) to the double bond of the substrate constitutes a stabilized cyclopropylmethyl cation.[1] This "nonclassical" species is prone to rearrange to the corresponding cyclobutenyl cation complex which likely has some carbene character[11] and evolves by 1,2-hydrogen shift to the final product. This interpretation gains credence by the deuterium-labeling experiment depicted in Scheme 3. In line with the proposed mechanism, product **4-D** is exclusively labeled at the 2-position, with a deuterium incorporation of ≥97% (NMR).

Scheme 1. $PtCl_2$-Catalyzed Cyclobutene Formation

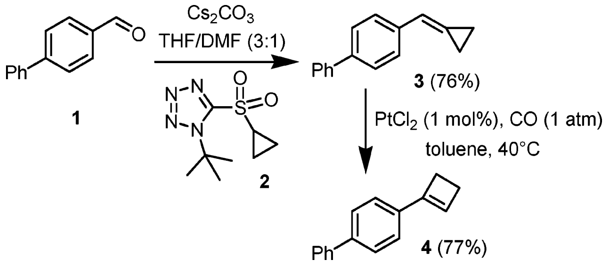
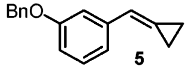
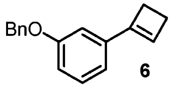
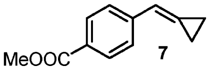
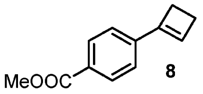
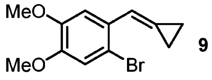
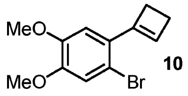
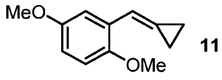
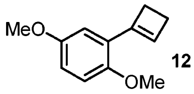
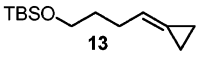
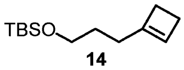
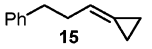
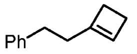
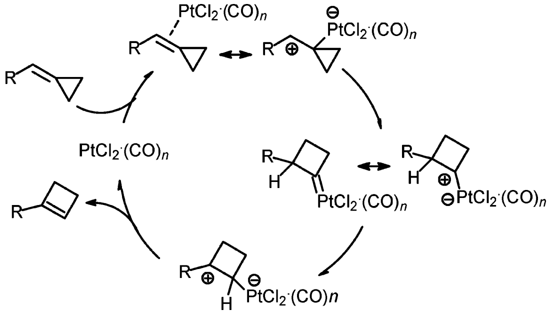


Table 1. Cyclobutenes by $PtCl_2$-Catalyzed Rearrangement of Alkylidenecyclopropanes[a]

Nr		Product	Yield
1	 **5**	 **6**	90%
2	 **7**	 **8**	80%
3	 **9**	 **10**	61%
4	 **11**	 **12**	50%[b]
5	 **13**	 **14**	93%
6	 **15**	 **16**	95%

[a] All reactions were performed with $PtCl_2$ (5 mol %) in toluene (0.1 M) at 80 °C under CO (1 atm) unless stated otherwise. [b] $c = 0.02$ M.

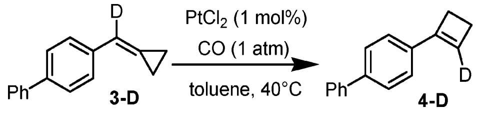
Scheme 2. Proposed Mechanism



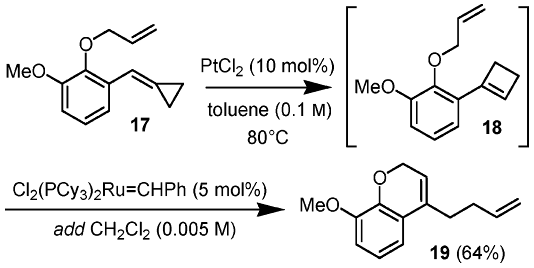
The novel cyclobutene formation can be linked to further catalytic transformations. Thus, addition of Grubbs catalyst (5 mol %)[12] and CH_2Cl_2 to the crude mixture formed upon $PtCl_2$-catalyzed rearrangement of substrate **17** bearing an allyl ether entity led to chromene **19** in good overall yield. This product originates from an efficient ROM/RCM cascade[13] of cyclobutene **18** initially formed (Scheme 4).

10.1021/ja061392y CCC: $33.50

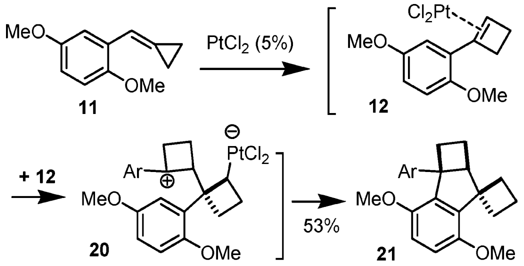
Scheme 3. Deuterium-Labeling Experiment



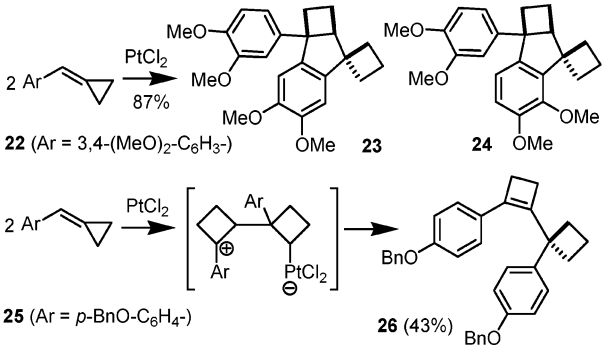
Scheme 4. Cyclobutene Formation/ROM/RCM Cascade



Scheme 5. PtCl$_2$-Catalyzed Dimerization



Scheme 6. Cyclodimerizations of Electron-Rich Substrates



Yet other possibilities were encountered when the PtCl$_2$-catalyzed rearrangement was applied to substrates bearing very electron-rich arene substituents. Even though compound **11** provides the corresponding cyclobutene **12** in reasonable yield (cf. Table 1, entry 4), the dimeric product **21** is obtained when the reaction is performed at higher concentrations (Scheme 5). The unusual structure of this compound was unambiguously elucidated by extensive NMR investigations (cf. Supporting Information). Its formation is readily explained by assuming that the Pt(2+) template is not only able to activate the starting alkylidenecyclopropane but can similarly also activate the double bond of the resulting primary product **12**. Attack of a second molecule of **12** then leads to the putative zwitterionic intermediate **20** which undergoes a Friedel−Crafts alkylation of one of the arene rings on its own backbone.[14] The ensuing re-aromatization furnishes the proton necessary to release the catalyst.

The same behavior was observed for compound **22** which affords product **23** and its regioisomer **24** (dr = 9:1) in 87% combined yield (Scheme 6). This mechanistic proposal also accounts for the observation that substrate **25** provides the dimeric olefin **26** which likely originates from the same type of zwitterionic intermediate. Since the arene in **25** is somewhat less activated, elimination by loss of proton outperforms the Friedel−Crafts pathway and leads to the observed product **26**.

In summary, we have shown that alkylidenecyclopropanes, on activation with catalytic amounts of PtCl$_2$ or, preferentially, PtCl$_2$/CO (1 atm), undergo previously unknown ring expansions, thus opening a convenient new entry into variously substituted cyclobutenes and derivatives thereof. Further investigations on this and related types of noble metal-catalyzed rearrangements are ongoing and will be reported in due course.

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Supporting Information Available: Experimental details, including the formation of alkylidenecyclopropanes by Julia−Kocienski olefination. This material is available free of charge via the Internet at http://pubs.acs.org

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(7) In contrast to PtCl$_2$, gold catalysts [AuCl, AuCl$_3$, (PPh$_3$)AuCl, (PPh$_3$)AuNTf$_2$] gave less than 10% conversion when applied to substrate **7**. Moreover, control experiments showed no cyclobutene formation upon simple heating of the substrate in toluene in the absence of PtCl$_2$.

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