Pergamon

Tetrahedron Letters, Vol. 38, No. 42, pp. 7425-7428, 1997

0040-4039/97 $17.00 + 0.00

PII: S0040-4039(97)01747-4

Functionalized Alkylidenecyclopentenes by Acid-Catalyzed Electrocyclic Ring Closure of (2Z)-(Di)vinylallene Acetals

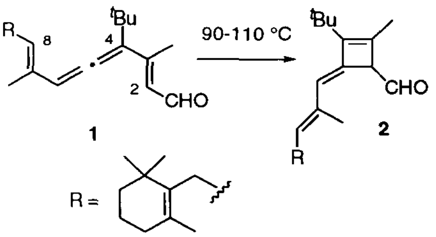
Angel R. de Lera,*[1] José García Rey,[2] David Hrovat,[3] Beatriz Iglesias,[1] and Susana López[2]

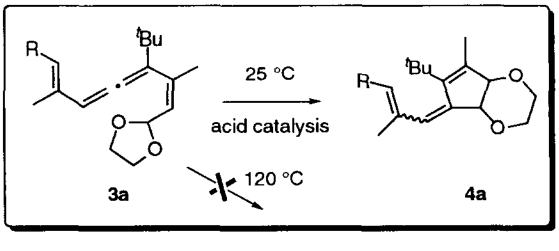
[1]Departamento de Química Física y Química Orgánica, Universidad de Vigo, 36200 Vigo, SPAIN
[2]Departamento de Química Orgánica, Universidad de Santiago de Compostela, 15706 Santiago, SPAIN
[3]Department of Chemistry, University of Washington, Seattle, WA 98195, USA

Abstract: Acid-induced electrocyclic ring-closure of (2Z)-4-*tert*-butyl-3-methyl-2,4,5,7-tetraene acetals **3** afforded a mixture of alkylidenecyclopentene dioxanes *Z*-**4** and *E*-**4**. The lack of torquoselective effects on the electrocyclization suggested the transition state structures for the two alternative conrotatory modes to have similar energies. The results of an *ab initio* study of a model system at the DFT B3LYP/6-31G* level were consistent with this hypothesis.

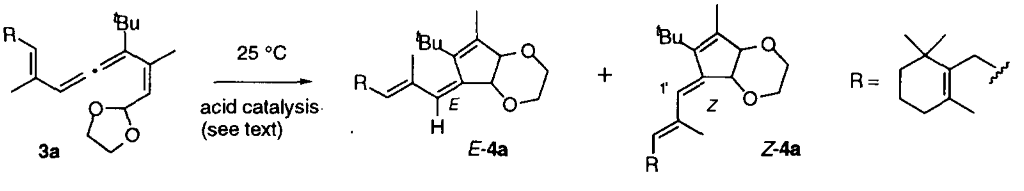
The presence of charged atoms in the structure of a compound can substantially decrease the free energy of activation of molecular rearrangements.[1] This is due to a combination of often related factors, including, in addition to the electronic effects of the empty or filled orbitals, enthalpic driving force, diversion of reaction pathways through a non-concerted alternative, and greater delocalization of charge in the transition state.[1] Examples of rate acceleration attributed to these effects are abundant among sigmatropic rearrangements, particularly [3,3]-sigmatropic shifts (including aza-Cope) and ene-cyclizations, both of which can afford a variety of ring systems, often with high degrees of stereochemical control.[1,2]

In connection with a broader study of the structural effects of substituents on the thermal rearrangements of divinylallenes,[3] we considered that changing the terminal vinyl aldehyde of **1** from *E* to *Z* geometry might reverse the regioselectivity of its thermal cyclization, so that it occurred at its less-substituted vinylallene C_5-C_8, rather than at the sterically congested terminus bearing the *tert*-butyl group.[3] In the light of results indicating that (2Z)-(di)vinylallenes with a methylene group at C_1 could undergo other pericyclic reactions (mainly [1,5] sigmatropic shifts of hydrogen)[4a] and that (2Z)-divinylallenals experienced facile 6e$^-$-electrocyclic ring closure to alkylidene-2*H*-pyrans,[4b] we decided to study the corresponding acetals **3**. However, to our surprise, divinylallene acetal **3a** failed to cyclize at either of its vinylallene subunits upon prolonged heating in deuterobenzene (sealed tube, 24 h at 120 °C).

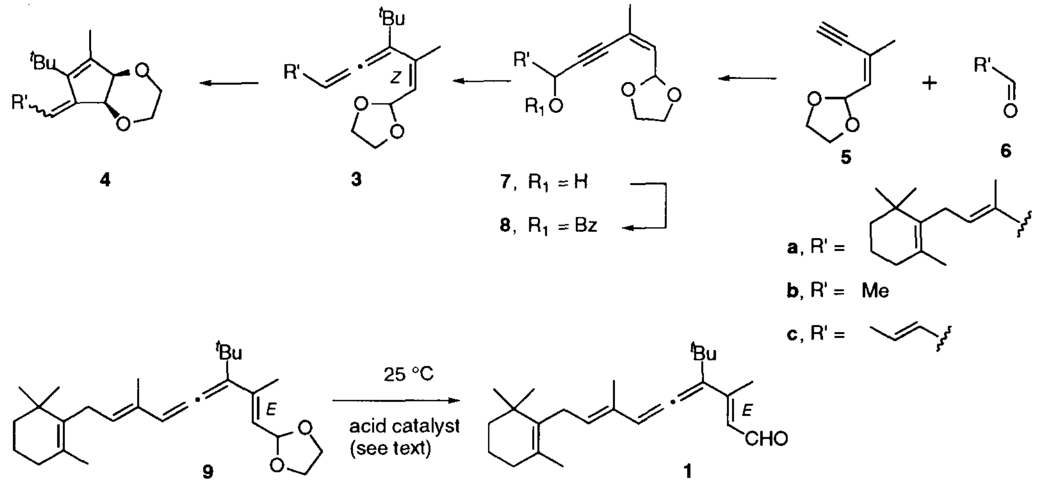




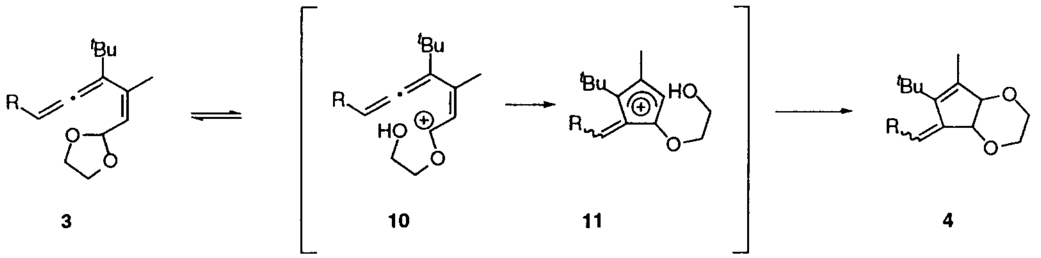
Unexpectedly, attempts to obtain the corresponding aldehyde from **3a** using a variety of mild deprotection conditions[5] led to a roughly 1:1 mixture of two isomeric products in short reaction times (5-30 min) and almost quantitative yield. These products were later identified as *E*- and *Z*-alkylidenecyclopentenes **4a** by means of ^{1}H and ^{13}C NMR spectroscopy. These stereochemical assignments were confirmed by the results of nOe difference experiments, especially the observation of enhancement of the signal for $H_{1'}$ upon saturation of the *tert*-butyl group in *Z*-**4a**.



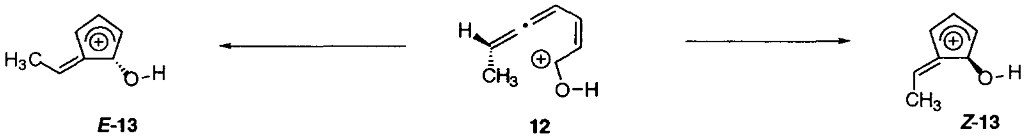
Vinylallene acetal **3b** and divinylallene acetal **3c** also underwent this rearrangement, affording, after chromatographic separation, *E*- and *Z*-alkylidenecyclopentenes **4b** and **4c**, respectively, in high yield (92-96%).[6] Thus, the reaction is not dependent on the presence of a second vinyl group. However, the 2*Z* geometry of the vinylallene is necessary for the rearrangement, since, under standard deprotection conditions,[5a] the 2*E*-isomer of **3a** (compound **9**) cleanly gave the known divinylallenal **1**[3c] in 94% yield. Appropriate orientation of the functional groups is thus an important determinant of the reaction pathway.

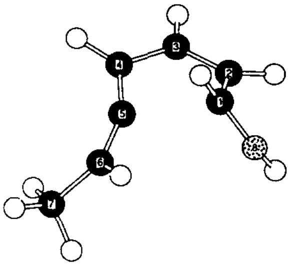


A plausible mechanism for this rearrangement might entail initial formation of conjugated vinylallenyl (*i.e.* dienyl) carbocation **10**, followed by a Nazarov-type 4e$^-$-electrocyclic ring closure[8] to allylic-type cation **11**, and trapping by the hydroxyether side-chain. This mechanism is reminiscent of that described by Tius for the solvolysis of methoxyallenyl alcohols,[9] which also involves electrocyclic ring-closure of a 1-oxypentadienylic cation, but leads to α-methylenecyclopentenones (rather than alkylidenecyclopentene-dioxanes) owing to the different array of functional groups at the periphery of the intermediate cation.

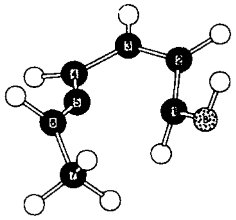


This acid-catalyzed cyclopentannulation apparently lacks the torquoselectivity of the cyclization of divinylallenes to alkylidenecycobutenes process (**1**-->**2**), suggesting that here the bulky *tert*-butyl group (the main factor controlling the stereochemistry in **1**-->**2**)[3b,c] has virtually no stereochemical influence on the cyclization. This, in its turn, suggested that the transition states for the *inward* and *outward* conrotatory cyclization modes are similar. To confirm that the proposed mechanism was consistent with this hypothesis, we carried out *ab initio* calculations at the DFT B3LYP/6-31G* level,[10,11] on the two alternative transition-state structures (TS) of model vinylallenium cation **12**. The difference in activation energies for the two TS was negligible, the formation of *E*-**13** being favored over that of *Z*-**13** by 0.56 kcal/mol. The activation energies (7.86 kcal/mol and 8.41 kcal/mol for *E*-**13** and *Z*-**13**, respectively) were small and similar to the values of 9.9 kcal/mol and 1.3 kcal/mol, calculated at the RHF/3-21G and MP2/6-31G* levels of theory, respectively, by Houk[12] in a study of the gas-phase electrocyclization TS of pentadienylcations.





Z-**14**



E-**14**

In summary, we report a new variant of the Nazarov cyclization[13] in which divinylallene acetals undergo facile rearrangement to alkylidenecyclopentenes by a mechanism consistent with electrocyclic ring-closure of a pentadienyl carbocation. Work to explore the synthetic potential of this reaction, including examination of its stereochemical aspects and the effects of using other acetal protecting groups, is in progress.[14]

Acknowledgments. We thank FIS (Contract 95/1534) and *Xunta de Galicia* (grant XUGA20904B95; fellowship to J.G.R.) for financial support and Profs. Wes Borden and F. Cossío for encouragement and use of computer resources.

References

1. (a) Overman, L. E. *Acc. Chem. Res.* **1992**, *25*, 352. (b) Gassman, P. A.; Singleton, D. A. *J. Am. Chem. Soc.* **1984**, *106*, 6085. (c) Harvey, D. F.; Grenzer, E. M. *J. Org. Chem.* **1996**, *61*, 159.

2. Thebtaranonth, C.; Thebtaranonth, Y. *Cyclization Reactions*; CRC Press: Boca Raton, FL, 1994.

3. (a) García Rey, J.; Rodríguez, J.; de Lera, A. R. *Tetrahedron Lett.* **1993**, *34*, 6293. (b) López, S.; García Rey, J. ; Rodríguez, J.; de Lera, A. R. *Tetrahedron Lett.* **1995**, *36*, 4669. (c) López, S.; Rodríguez, J.; García Rey, J.; de Lera, A. R. *J. Am. Chem. Soc.* **1996**, *118*, 1881.

4. (a) Okamura, W. H. *Acc. Chem. Res.* **1983**, *16*, 81. (b) de Lera, A. R.; Torrado, A.; García Rey, J.; López, S., previous article in this issue.

5. Some of the deprotection conditions are listed below. For general references, see: Greene, T. W.; Wuts, P. G. M. *Protective Groups in Organic Synthesis*; Wiley: New York, 1991. Kocienski, P. J. *Protecting Groups*; Georg Thieme Verlag: Stuttgart, 1994.

   (a) *p*-TsOH, acetone/H_2O, 25 °C, 10 min. (b) $FeCl_3 \cdot SiO_2$, $CHCl_3$, 25 °C, 30 min. (c) $LiBF_4$, CH_3CN (2% H_2O), 25 °C, 30 min. (d) $LiClO_4$, Et_2O, 25 °C, 60 min. (e) $PdCl_2(CH_3CN)_2$, acetone, 25 °C, 10 min. (f) $PdCl_2(CH_3CN)_2$, CH_3CN, 25 °C, 30 min.

6. Note: The starting acetals were prepared following our usual procedure (ref. 3), by S_N2' reaction of dilithium di-*tert*-butylcyanocuprate with propargylic benzoates **8**, which were obtained, uneventfully, by coupling of aldehydes **6** with the known enyne acetal **5** (ref. 7) followed by esterification of the propargyl alcohols **7**.

7. Abrams, G. D.; Abrams, S. R.; Nelson, L. A. K.; Gusta, L. V. *Tetrahedron* **1990**, *46*, 5543.

8. (a) Denmark, S. E. Nazarov and Related Cationic Cyclizations, in *Comprehensive Organic Synthesis*, Vol. 5; Trost, B. M.; Fleming, I.; Paquette, L. A., Eds. Pergamon Press: Oxford, 1991, pp. 751-784. (b) Habermas, K. L.; Denmark, S. E.; Jones, T. K. The Nazarov Cyclization, in *Organic Reactions*, vol. 45; Paquette, L. A., Ed.; Wiley: New York, 1994, pp. 1-158.

9. (a) Tius, M. A.; Astrab, D. P. *Tetrahedron Lett.* **1984**, *25*, 1539. (b) Tius, M. A.; Astrab, D. P.; Fauq, A. H.; Ousset, J-B.; Trehan, S. *J. Am. Chem. Soc.* **1986**, *108*, 3438. (c) Tius, M. A.; Drake, D. J. *Tetrahedron* **1996**, *52*, 14651.

10. (a) Ziegler, T. *Chem. Rev.* **1991**, *91*, 651. (b) For a description of the density functionals as implemented in the Gaussian series of programs, see: Johnson, B. G.; Gill, P. M. W.; Pople, J. A. *J. Chem. Phys.* **1993**, *98*, 5612.

11. Gaussian 94 (Revision A.1). Frisch, M. J.; Trucks, G. W.; Schlegel, H. B.; Gill, P. M. W.; Johnson, B. G.; Robb, M. A.; Cheeseman, J. R.; Keith, T. A.; Petersson, G. A.; Montgomery, J. A.; Raghavachari, K.; Al-Laham, M. A.; Zakrzewski, V. G.; Ortiz, J. V.; Foresman, J. B.; Cioslowski, J.; Stefanov, B. B.; Nanayakkara, A.; Challacombe, M.; Peng, C. Y.; Ayala, P. Y.; Chen, W.; Wong, M. W.; Andres, J. L.; Replogle, E. S.; Gomperts, R.; Martin, R. L.; Fox, D. J.; Binkley, J. S.; Defrees, D. J.; Baker, J.; Stewart, J. P.; Head-Gordon, M.; Gonzalez, C.; Pople, J. A. Gaussian, Inc.: Pittsburgh, PA, 1995.

12. Kallel, E. A.; Houk, K. N. *J. Org. Chem.* **1989**, *54*, 6006.

13. For other theoretical approaches to the Nazarov cyclization, see: (a) Smith, D. A.; Ulmer, C. W. *Tetrahedron Lett.* **1991**, *32*, 725. (b) Smith, D. A.; Ulmer, C. W. *J. Org. Chem.* **1991**, *56*, 4444. (c) Smith, D. A.; Ulmer, C. W. *J. Org. Chem.* **1993**, *58*, 4118.

14. Satisfactory spectroscopic data (^1H NMR, ^{13}C NMR, IR, UV) were obtained for all new substances reported in this paper. Elemental compositions were determined by high resolution mass spectroscopy after purification by HPLC.

(*Received in UK* 26 *June* 1997; *accepted* 22 *August* 1997)