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An Oxidative Prins–Pinacol Tandem Process and its Application to the synthesis of (−)-Platensimycin

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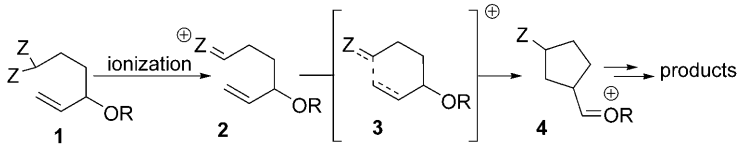
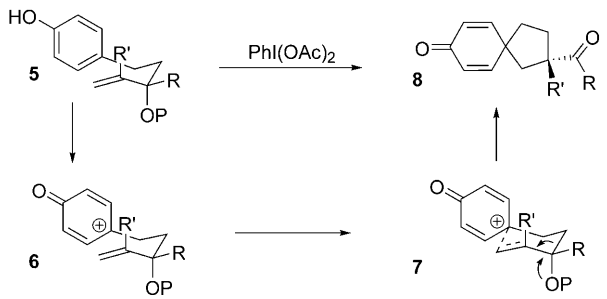
Cationic molecular rearrangements[1] provide an appealing avenue to complex molecular architectures. Noteworthy examples are apparent from the work of Overman, who harnessed the power of tandem Prins–pinacol rearrangement sequences in a number of brilliant syntheses.[2] As shown in Scheme 1, this process starts with the ionization of, for example, a ketal or thioketal (e.g. **1**, Z = OR, SR) under the influence of an appropriate promoter (e.g., Lewis acid, etc.). Nascent onium intermediate **2** is then intercepted by an olefinic π bond, which is part of an allylic alcohol or ether. This triggers a pinacol-like transposition leading to **4**, and thence to various possible products (Scheme 1).



Scheme 1. The Prins–pinacol process.

Our interest[3] in the oxidative dearomatization of electron-rich aromatics[4] mediated by hypervalent iodine reagents[5,6] led us to question whether an analogous process could be initiated by the oxidative activation of a phenol. Although phenols normally react as nucleophiles, oxidative activation converts them into reactive electrophiles, which may then be intercepted by appropriate nucleophilic traps. Such a reversal of reactivity is tantamount to an "aromatic ring umpolung."[3,7] To illustrate, oxidation of phenolic compound **5** would produce the electrophile rendered in Scheme 2 as phenoxonium ion **6**. Quideau,[5d] Nicolaou,[8] their co-workers, and us[3c,e] have shown that such reactive agents can be intercepted by allylsilanes. If the internal olefin were to add to the electrophilic carbon in **6**, then cationic intermediate **7** would be primed to undergo a pinacol rearrangement to, ultimately, carbonyl compound **8**, arguably through a cyclic, chair-like transition state that should permit control of the configuration of the emerging quaternary carbon.[9] Overall, a stereocontrolled "oxidative Prins–pinacol" tandem process would result. Herein, we describe methodology inducing such a transformation.



Scheme 2. The oxidative Prins–pinacol transformation. P = protecting group.

The feasibility of the tandem Prins–pinacol process was explored by using phenolic substrates **5a–d** (Table 1).[10] These compounds were exposed to the action of iodobenzene diacetate (DIB), an environmentally benign and inexpensive oxidant, in a mixture of dichloromethane and hexafluoroisopropanol (HFIP). The choice of HFIP was suggested by the noteworthy work of Kita and co-workers,[11] who have shown it to be especially well suited for many reactions involving hypervalent iodine reagents. Pleasingly, the anticipated ketones **8a–d** emerged in 58–68% yield. The reaction

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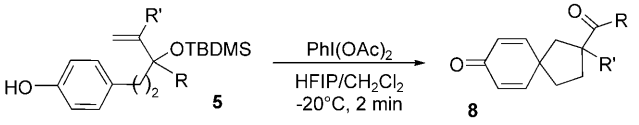
Table 1. The oxidative Prins–pinacol tandem reaction of olefinic substrates **5**.[a]

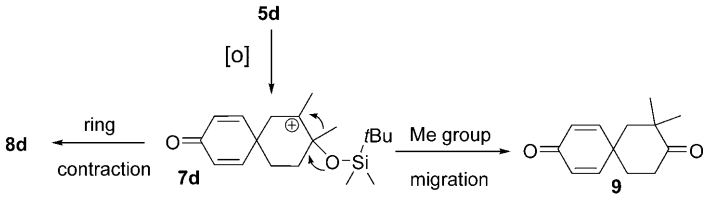


Entry	Reagent	R	R′	Yield [%]
1	**5a**	CH_3	H	64
2	**5b**	$CH{=}CH_2$	H	60
3	**5c**	Ph	CH_3	58
4	**5d**	CH_3	CH_3	68

[a] TBDMS = *tert*-butyldimethylsilyl.

simultaneously produces two quaternary carbons, one of which is also a spiro center. Furthermore, products **8a** and **d** incorporate a spiro[4.5]decanyl system of the type found in natural products such as anhydro-β-rotunol **10**[12] and scopadulcic acid **11** (Bz = benzoyl).[13] It should be noted that the

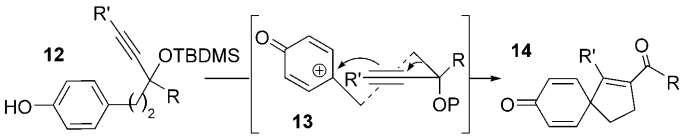
oxidative Prins–pinacol reaction of **8d** proceeded with formation of byproduct **9** (Scheme 3; 5–10% yield). The formation of such a spiro[5.5]undecanyl system is rationalized by invoking methyl migration from intermediate **7d**, occurring in competition with, but to a minor extent relative to, ring contraction.



Scheme 3. The formation of spiro[5.5]undecanyl byproduct **9**.

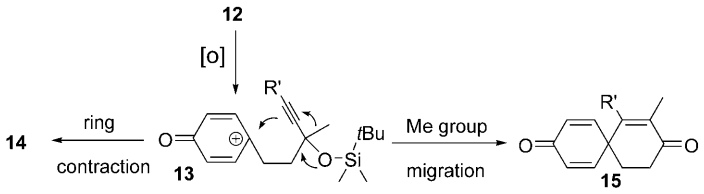
As delineated in Table 2, the transformation was readily extended to acetylenic substrates. The expected enones **14** were thus obtained in 48–55% yield, probably via a half-chair transition state such as **13**. It should be noted that terminal and internal alkynes undergo the reaction in almost identical yield (cf. **14a** vs. **14b–d)**. Enones **14** are sometimes accompanied by a small amount of byproduct **15** (5–10% yield, Scheme 4). As outlined earlier, its formation is probably a consequence of migration of the R group occurring in competition with the ring contraction, which remains the major reaction pathway.

Table 2. The oxidative Prins–pinacol tandem reaction of acetylenic substrates **12**.



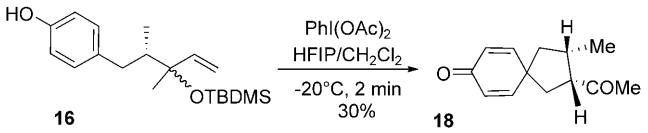
Entry	Reagent	R	R′	Yield [%]
1	**12a**	CH_3	H	51
2	**12b**	CH_3	*n*Bu	48
3	**12c**	CH_3	*n*-dec[a]	55
4	**12d**	≡—*n*-dec	*n*-dec[a]	50

[a] dec = decyl.



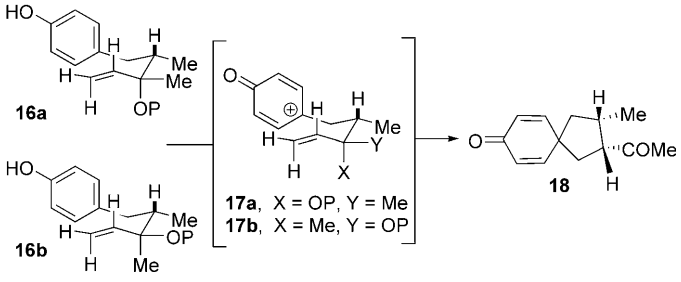
Scheme 4. The formation of spiro[5.5]undecanyl byproduct **15**.

Clues to the stereochemical course of the reaction emerged from experiments involving phenol **16** (Scheme 5). Treatment of a mixture of diastereomers of **16** with DIB in



Scheme 5.

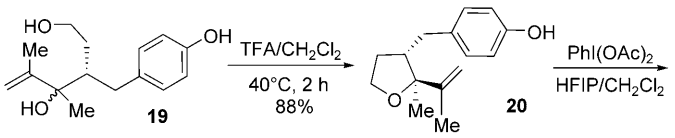
HFIP/DCM afforded *cis*-ketone **18**[14] via intermediate **17** in a low yield of 30%, about one-half of the yield recorded earlier for substrates **5** (Table 1). We attribute such poor efficiency to the fact that only one of the two diastereomers of **16** is a suitable substrate for the oxidative Prins–pinacol sequence. To illustrate (Scheme 6), the conformation of diastereomer **16a**, conducive to the occurrence of the reaction, is such that the OP group experiences an $A^{1,3}$ interaction with the "inside" vinylic hydrogen.[15] In diastereomer **16b**,

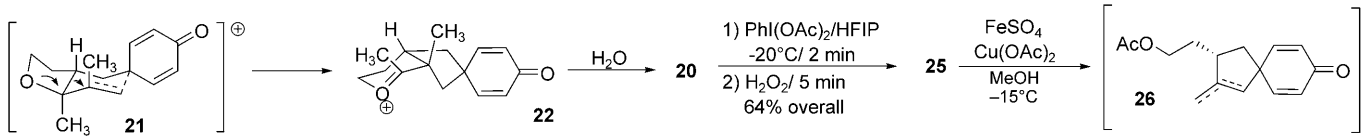


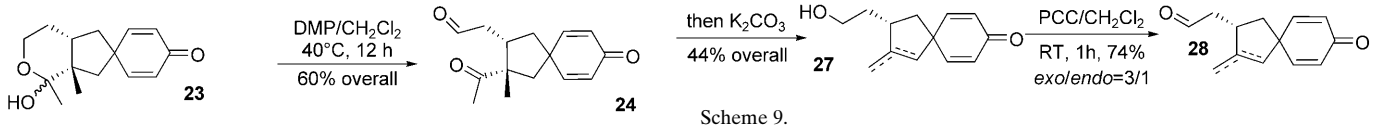
Scheme 6.

the analogous allylic interaction is considerably more severe in that it involves compression of a more sterically demanding Me group against the same vinylic hydrogen. In all likelihood, this retards the Prins reaction step and diverts the reactive electrophile created upon umpolung activation of the phenol towards other reaction pathways. In either case, the product of the reaction is *cis*-ketone **18**.[14]

Consistent with the aforementioned rationale, tetrahydrofuran **20** reacted with DIB, via intermediates **21** and **22**, to furnish compound **23** in considerably higher yield (70%, Scheme 7). Compound **20** emerged in 88% yield as a single





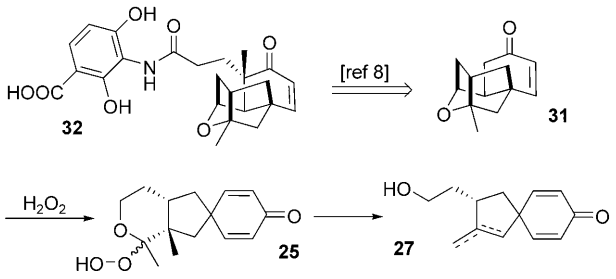


Scheme 7. TFA = trifluoroacetic acid; DMP = Dess–Martin periodinane.

diastereomer (presumably the thermodynamically more favorable one) upon acid treatment of triols **19**, which, in turn, were assembled by using Evans asymmetric alkylation technology.[10] We found it convenient to subject crude **23** to Dess–Martin's oxidation[16] and isolate and characterize ketoaldehyde **24**, which emerged in 60% overall yield as a single diastereomer. As anticipated, based upon our mechanistic hypothesis, compound **24** displayed a *cis* relative configuration of the carbonyl branches. The reaction had created contiguous tertiary and quaternary carbon centers with complete stereocontrol.

As an initial application of the oxidative Prins–pinacol tandem sequence, we now describe a formal total synthesis of (−)-platensimycin, **32** (Scheme 8). This substance is an exciting experimental antibiotic that is believed to act as a FabF inhibitor.[17a] Its unusual structure and potent bioactivity have elicited enormous interest within the synthetic community.[17] Our approach to **32** relies upon the assumption that one may reach hydroperoxide **25** by intercepting oxonium ion **22** with H_2O_2. Subsequent Schreiber–Fenton fragmentation[18] would provide alkenes **27**, which may be elaborated into advanced intermediate **31** as described by Nicolaou and co-workers.[8]

The hypothesis was put into practice as shown in Scheme 9. Oxidation of compound **20** with DIB, as detailed earlier, followed by the addition of 30% hydrogen peroxide, afforded a 3:2 mixture of unassigned diastereomers of hydroperoxyketal **25** in 64% overall yield. This material was immediately treated with $FeSO_4$ and $Cu(OAc)_2$ in MeOH to give **26**.

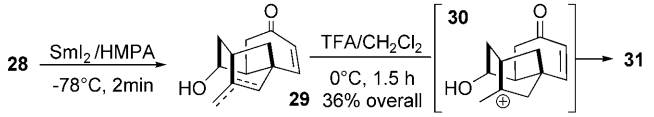


Scheme 8. The structure of (−)-platensimycin and retrosynthetic logic. PCC = pyridinium chlorochromate.

Scheme 9.

Addition of K_2CO_3 to the reaction mixture induced conversion into **27** in 44% overall yield from **25**. Compound **27** was obtained as a 3:1 mixture of exocyclic (major) and endocyclic alkenes. As first demonstrated by Nicolaou and coworkers,[8] both isomers converge to the tetracyclic core of platensimycin (**32**). Accordingly, no separation was required. The mixture of alcohols was thus advanced to a mixture of the corresponding aldehydes (**28**), in 74% yield, by PCC oxidation. Aldehydes **28** are known synthetic intermediates for (−)-platensimycin.[8] Hence, they were subjected to the action of Kagan's reagent (SmI_2),[19] whereupon stereoselective cyclization to alcohols **29** occurred (Scheme 10). Finally, the olefin regioisomers of **29** converged to the same final product **31** upon treatment with TFA. The elaboration of **31** into (−)-platensimycin is well documented in the literature.[8] Therefore, the synthesis of **31** represents a formal total synthesis of (−)-platensimycin.

In conclusion, our continuing investigations centering upon the concept of aromatic ring umpolung have now produced an unprecedented oxidative Prins–Pinacol tandem process. This method allows rapid, stereocontrolled elabora-



Scheme 10. HMPA = hexamethylphosphoramide.

tion of relatively simple phenols into functionalized spirocyclic compounds possessing quaternary carbon centers. The structures thus obtained are found as subunits of numerous natural products. A first application to the formal synthesis of (−)-platensimycin has been accomplished. Ongoing investigations into different aromatic derivatives involved in oxidative transposition processes as a rapid access to the main core of natural products will be disclosed in due course.

Acknowledgements

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Keywords: hypervalent compounds · iodine · natural products · oxidation · Prins–pinacol reaction · umpolung

[1] a) R. Fittig, *Justus Liebigs Ann. Chem.* **1860**, *114*, 54; b) G. Wagner, *J. Russ. Chem. Soc.* **1899**, *31*, 690; c) H. Meerwein, *Justus Liebigs Ann. Chem.* **1914**, *405*, 129; d) S. S. Nametkin, *Justus Liebigs Ann. Chem.* **1923**, *432*, 207; e) J. H. Hanson, *Comp. Org. Syn.* **1991**, *3*, 705.

[2] a) G. C. Hirst, T. O. Johnson, L. E. Overman, *J. Am. Chem. Soc.* **1993**, *115*, 2992; b) D. W. C. MacMillan, L. E. Overman, *J. Am. Chem. Soc.* **1995**, *117*, 10391; c) L. E. Overman, L. D. Pennington, *Can. J. Chem.* **2000**, *78*, 732; d) A. D. Lebsack, L. E. Overman, R. J. Valentkovitch, *J. Am. Chem. Soc.* **2001**, *123*, 4851; e) L. E. Overman E. J. Velthuisen, *J. Org. Chem.* **2006**, *71*, 1581; f) A. Armstrong, Y. Bhonoah, S. E. Shanahan, *J. Org. Chem.* **2007**, *72*, 8019; g) L. E. Overman, L. D. Pennington, *J. Org. Chem.* **2003**, *68*, 7143.

[3] a) D. Bérard, M. A. Giroux, L. Racicot, C. Sabot, S. Canesi, *Tetrahedron* **2008**, *64*, 7537; b) C. Sabot, D. Bérard, S. Canesi, *Org. Lett.* **2008**, *10*, 4629; c) C. Sabot, B. Commare, S. Nahi, M. A. Duceppe, K. C. Guérard, S. Canesi, *Synlett* **2008**, 3226; d) K. C. Guérard, C. Sabot, L. Racicot, S. Canesi, *J. Org. Chem.* **2009**, *74*, 2039; e) C. Sabot, K. C. Guérard, S. Canesi, *Chem. Commun.* **2009**, 2941; f) K. C. Guérard, C. Chapelle, M. A. Giroux, C. Sabot, M. A. Beaulieu, N. Achache, S. Canesi, *Org. Lett.* **2009**, *11*, 4756; g) K. C. Guérard, C. Sabot, M. A. Beaulieu, M. A. Giroux, S. Canesi, *Tetrahedron* **2010**, *66*, 5893.

[4] a) T. Wirth, *Top. Curr. Chem.* **2003**, *224*; b) M. A. Ciufolini, N. A. Braun, S. Canesi, M. Ousmer, J. Chang, D. Chai, *Synthesis* **2007**, 3759; c) V. Zhdankin, P. J. Stang, *Chem. Rev.* **2008**, *108*, 5299; d) L. Pouységu, D. Deffieux, S. Quideau, *Tetrahedron* **2010**, *66*, 2235.

[5] a) B. D. Gates, P. Dalidowicz, A. Tebben, S. Wang, J. S. Swenton, *J. Org. Chem.* **1992**, *57*, 2135; b) J. S. Swenton, A. Callinan, Y. Chen, J. J. Rohde, M. L. Kearns, G. W. Morrow, *J. Org. Chem.* **1996**, *61*, 1267; c) N. A. Braun, M. A. Ciufolini, K. Peters, E. M. Peters, *Tetrahedron Lett.* **1998**, *39*, 4667; d) S. Quideau, M. A. Looney, L. Pouységu, *Org. Lett.* **1999**, *1*, 1651; e) N. A. Braun, J. Bray, M. Ousmer, K. Peters, E. M. Peters, D. Bouchu, M. A. Ciufolini, *J. Org. Chem.* **2000**, *65*, 4397; f) G. Scheffler, H. Seike, E. J. Sorensen, *Angew. Chem.* **2000**, *112*, 4783; *Angew. Chem. Int. Ed.* **2000**, *39*, 4593; g) M. Ousmer, N. A. Braun, C. Bavoux, M. Perrin, M. A. Ciufolini, *J. Am. Chem. Soc.* **2001**, *123*, 7534; h) S. Quideau, L. Pouységu, M. Oxoby, M. A. Looney, *Tetrahedron* **2001**, *57*, 319; i) S. Canesi, P. Belmont, D. Bouchu, L. Rousset, M. A. Ciufolini, *Tetrahedron Lett.* **2002**, *43*, 5193; j) S. Canesi, D. Bouchu, M. A. Ciufolini, *Angew. Chem.* **2004**, *116*, 4436; *Angew. Chem. Int. Ed.* **2004**, *43*, 4336; k) S. Quideau, L. Pouységu, D. Deffieux, *Curr. Org. Chem.* **2004**, *8*, 113; l) S. Canesi, D. Bouchu, M. A. Ciufolini, *Org. Lett.* **2005**, *7*, 175; m) T. Honda, H. Shigehisa, *Org. Lett.* **2006**, *8*, 657; n) S. Quideau, L. Pouységu, D. Deffieux, *Synlett* **2008**, 467; o) H. Liang, M. A. Ciufolini, *J. Org. Chem.* **2008**, *73*, 4299; p) M. A. Giroux, K. C. Guérard, M. A. Beaulieu, C. Sabot, S. Canesi, *Eur. J. Org. Chem.* **2009**, 3871; q) B. A. Mendelsohn, M. A. Ciufolini, *Org. Lett.* **2009**, *11*, 4736; r) M. Traoré, S. Ahmed-Ali, M. Peuchmaur, Y. S. Wong, *Tetrahedron* **2010**, *66*, 5863; s) H. Liang, M. A. Ciufolini, *Tetrahedron* **2010**, *66*, 5884; t) L. Pouységu, T. Sylla, T. Garnier, L. B. Rojas, J. Charris, D. Deffieux, S. Quideau, *Tetrahedron* **2010**, *66*, 5908.

[6] a) A. Pelter, R. A. Drake, *Tetrahedron Lett.* **1988**, *29*, 4181; b) S. Quideau, M. A. Looney, L. Pouységu, *J. Org. Chem.* **1998**, *63*, 9597; c) A. Ozanne-Beaudenon, S. Quideau, *Angew. Chem.* **2005**, *117*, 7227; *Angew. Chem. Int. Ed.* **2005**, *44*, 7065; d) M. A. Ciufolini, S. Canesi, M. Ousmer, N. A. Braun, *Tetrahedron* **2006**, *62*, 5318; e) D. Bérard, A. Jean, S. Canesi, *Tetrahedron Lett.* **2007**, *48*, 8238; f) A. Jean, J. Cantat, D. Bérard, D. Bouchu, S. Canesi, *Org. Lett.* **2007**, *9*, 2553; g) L. Pouységu, S. Chassaing, D. Dejugnac, A. M. Lamidey, K. Miqueu, J. M. Sotiropoulos, S. Quideau, *Angew. Chem.* **2008**, *120*, 3608; *Angew. Chem. Int. Ed.* **2008**, *47*, 3552; h) D. Bérard, L. Racicot, C. Sabot, S. Canesi, *Synlett* **2008**, 1076; i) L. Pouységu, M. Marguerit, J. Gagnepain, G. Lyvinec, A. J. Eatherton, S. Quideau, *Org. Lett.* **2008**, *10*, 5211; j) B. A. Mendelsohn, S. Lee, S. Kim, F. Teyssier, V. S. Aulakh, M. A. Ciufolini, *Org. Lett.* **2009**, *11*, 1539; k) S. Quideau, G. Lyvinec, M. Marguerit, K. Bathany, A. Ozanne-Beaudenon, T. Bufeteau, D. Cavagnat, A. Chenede, *Angew. Chem.* **2009**, *121*, 4675; *Angew. Chem. Int. Ed.* **2009**, *48*, 4605; l) H. Liang, M. A. Ciufolini, *Org. Lett.* **2010**, *12*, 1760.

[7] a) D. Seebach, E. J. Corey, *J. Org. Chem.* **1975**, *40*, 231; b) D. Seebach, *Angew. Chem.* **1979**, *91*, 259; *Angew. Chem. Int. Ed. Engl.* **1979**, *18*, 239.

[8] K. C. Nicolaou, A. Li, D. J. Edmonds, G. S. Tria, S. P. Ellery, *J. Am. Chem. Soc.* **2009**, *131*, 16905.

[9] a) *Quaternary Stereocenters: Challenges and Solutions for Organic Synthesis* (Eds.: J. Christoffers, A. Baro), Wiley-VCH, Weinheim, **2005**; b) J. Christoffers, A. Mann, *Angew. Chem.* **2001**, *113*, 4725; *Angew. Chem. Int. Ed.* **2001**, *40*, 4591; c) J. Christoffers, A. Baro, *Angew. Chem.* **2003**, *115*, 1726; *Angew. Chem. Int. Ed.* **2003**, *42*, 1688; d) E. J. Corey, A. Guzman-Perez, *Angew. Chem.* **1998**, *110*, 2092; *Angew. Chem. Int. Ed.* **1998**, *37*, 388; e) I. Denissova, L. Barriault, *Tetrahedron* **2003**, *59*, 10105; f) A. Steven, L. E. Overman, *Angew. Chem.* **2007**, *119*, 5584; *Angew. Chem. Int. Ed.* **2007**, *46*, 5488.

[10] The preparation of these materials is provided in the Supporting Information.

[11] a) Y. Tamura, T. Yakura, J. Haruta, Y. Kita, *J. Org. Chem.* **1987**, *52*, 3927; b) Y. Kita, H. Tohma, K. Hatanaka, T. Takada, S. Fujita, S. Mitoh, H. Sakurai, S. Oka, *J. Am. Chem. Soc.* **1994**, *116*, 3684; c) Y. Kita, T. Takada, M. Gyoten, H. Tohma, M. H. Zenk, J. Eichhorn, *J. Org. Chem.* **1996**, *61*, 5854; d) Y. Kita, M. Gyoten, M. Ohtsubo, H. Tohma, T. Takada, *Chem. Commun.* **1996**, 1481; e) T. Takada, M. Arisawa, M. Gyoten, R. Hamada, H. Tohma, Y. Kita, *J. Org. Chem.* **1998**, *63*, 7698; f) M. Arisawa, S. Utsumi, M. Nakajima, N. G. Ramesh, H. Tohma, Y. Kita, *Chem. Commun.* **1999**, 469; g) S. Akai, N. Kawashita, N. Morita, Y. Nakamura, K. Iio, Y. Kita, *Heterocycles* **2002**, *58*, 75; h) T. Dohi, A. Maruyama, N. Takenaga, K. Senami, Y. Minamitsuji, H. Fujioka, S. B. Caemmerer, Y. Kita, *Angew. Chem.* **2008**, *120*, 3847; *Angew. Chem. Int. Ed.* **2008**, *47*, 3787; i) T. Dohi, Y. Kita, *Chem. Commun.* **2009**, 2073; j) T. Dohi, M. Ito, N. Yamaoka, K. Morimoto, H. Fujioka, Y. Kita, *Tetrahedron* **2009**, *65*, 10797; k) H. Fujioka, H. Komatsu, T. Nakamura, A. Miyoshi, K. Hata, J. Ganesh, K. Murai, Y. Kita, *Chem. Commun.* **2010**, *46*, 4133; l) T. Dohi, N. Yamaoka, Y. Kita, *Tetrahedron* **2010**, *66*, 5775.

[12] D. T. Coxon, K. R. Price, B. Howard, S. F. Osman, E. B. Kalan, R. M. Zacharius, *Tetrahedron Lett.* **1974**, *15*, 2921.

[13] a) M. Ahmed, J. Jakupovic, *Phytochemistry* **1990**, *29*, 3035; b) D. J. Kucera, S. J. O'Connor, L. E Overman, *J. Org. Chem.* **1993**, *58*, 5304; c) L. E. Overman, D. J. Ricca, V. D. Tran, *J. Am. Chem. Soc.*

1993, *115*, 2042; d) F. E. Ziegler, O. B. Wallace, *J. Org. Chem.* **1995**, *60*, 3626; e) L. E. Overman, D. J. Ricca, V. D. Tran, *J. Am. Chem. Soc.* **1997**, *119*, 12032; f) M. E. Fox, C. Li, J. P. Marino, L. E. Overman, *J. Am. Chem. Soc.* **1999**, *121*, 5467.

[14] For NMR studies on the stereochemistry of 1-acetyl-2-methylcyclopentane, see: a) M. J. Jorgenson, A. J. Brattesani, *J. Org. Chem.* **1969**, *34*, 1103; b) M. Tanaka, M. Imai, M. Fujio, E. Sakamoto, M. Takahashi, Y. Eto-Kato, X. M. Wu, K. Funakoshi, K. Sakai, H. Suemune, *J. Org. Chem.* **2000**, *65*, 5806; c) S. J. Degrado, H. Mizutani, A. H. Hoveyda, *J. Am. Chem. Soc.* **2002**, *124*, 13362.

[15] F. Johnson, *Chem. Rev.* **1965**, *65*, 375.

[16] D. B. Dess, J. C. Martin, *J. Org. Chem.* **1983**, *48*, 4155.

[17] a) J. Wang, *Nature* **2006**, *441*, 358; b) S. Xing, W. Pan, C. Liu, J. Ren, Z. Wang, *Angew. Chem.* **2010**, *122*, 3283; *Angew. Chem. Int. Ed.* **2010**, *49*, 3215; c) K. C. Nicolaou, A. Li, D. J. Edmonds, *Angew. Chem.* **2006**, *118*, 7244; *Angew. Chem. Int. Ed.* **2006**, *45*, 7086; d) K. C. Nicolaou, D. J. Edmonds, A. Li, G. S. Tria, *Angew. Chem.* **2007**, *119*, 4016; *Angew. Chem. Int. Ed.* **2007**, *46*, 3942; e) Y. Zou, C. H. Chen, C. D. Taylor, B. M. Foxman, B. B. Snider, *Org. Lett.* **2007**, *9*, 1825; f) K. C. Nicolaou, Y. Tang, J. Wang, *Chem. Commun.* **2007**, 1922; g) P. Li, J. N. Payette, H. Yamamoto, *J. Am. Chem. Soc.* **2007**, *129*, 9534; h) G. Lalic, E. J. Corey, *Org. Lett.* **2007**, *9*, 4921; i) K. Tiefenbacher, J. Mulzer, *Angew. Chem.* **2007**, *119*, 8220; *Angew. Chem. Int. Ed.* **2007**, *46*, 8074; j) K. C. Nicolaou, D. Pappo, K. Y. Tsang, R. Gibe, D. Y. K. Chen, *Angew. Chem.* **2008**, *120*, 958; *Angew. Chem. Int. Ed.* **2008**, *47*, 944; k) C. H. Kim, K. P. Jang, S. Y. Choi, Y. K. Chung, E. Lee, *Angew. Chem.* **2008**, *120*, 4073; *Angew. Chem. Int. Ed.* **2008**, *47*, 4009; l) J. I. Matsuo, K. Takeuchi, H. Ishibashi, *Org. Lett.* **2008**, *10*, 4049; m) A. K. Ghosh, K. Xi, *J. Org. Chem.* **2009**, *74*, 1163; n) S. Y. Yun, J. C. Zheng, D. Lee, *J. Am. Chem. Soc.* **2009**, *131*, 8413; o) K. C. Nicolaou, J. S. Chen, D. J. Edmonds, A. A. Estrada, *Angew. Chem.* **2009**, *121*, 670; *Angew. Chem. Int. Ed.* **2009**, *48*, 660; p) K. Tiefenbacher, J. Mulzer, *Angew. Chem.* **2008**, *120*, 2582; *Angew. Chem. Int. Ed.* **2008**, *47*, 2548; q) N. A. McGrath, E. S. Bartlett, S. Sittihan, J. T. Njardarson, *Angew. Chem.* **2009**, *121*, 8695; *Angew. Chem. Int. Ed.* **2009**, *48*, 8543.

[18] a) S. L. Schreiber, *J. Am. Chem. Soc.* **1980**, *102*, 6163; b) S. L. Schreiber, *J. Am. Chem. Soc.* **1985**, *107*, 2980; c) P. A. Christenson, *Tetrahedron* **1988**, *44*, 1925; d) S. Canesi, G. Berthiaume, P. Deslongchamps, *Eur. J. Org. Chem.* **2009**, 3871; e) P. Vlad, *Russ. Chem. Bull.* **2005**, *54*, 2656.

[19] a) G. A. Molander, *Chem. Rev.* **1992**, *92*, 29; b) K. C. Nicolaou, S. P. Ellery, J. S. Chen, *Angew. Chem.* **2009**, *121*, 7276; *Angew. Chem. Int. Ed.* **2009**, *48*, 7140.

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